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Journal of Sedimentary Petrology

A Publication of the Society of Economic Paleontologists and Mineralogists
a Division of
The American Association of Petroleum Geologists

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Journal of Sedimentary Petrology

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NOTICE

Articles submitted for publication to the *Journal of Sedimentary Petrology* should have a prefatory abstract and sufficient postage should be sent by the author to pay the return of the manuscript as it has been found that many articles require more or less revision before publication.

Persons who are not members of the Society of Economic Paleontologists and Mineralogists or are not subscribers to the *Journal of Sedimentary Petrology* but who desire to publish an article in the *Journal*, should have some member of the Society of Economic Paleontologists and Mineralogists or some member of the American Association of Petroleum Geologists sponsor the article. Members of these Societies are given preference in publication.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 14, NO. 2, PP. 43–69
FIGS 1–20, TABLES 1–2, AUGUST, 1944

MECHANICAL ANALYSIS OF SOME BOTTOM DEPOSITS OF THE NORTHERN RED SEA

N. M. SHUKRI AND R. A. HIGAZY
Faculty of Science, Cairo

ABSTRACT

The following account is an investigation of the mechanical composition of some sixty bottom samples from the Northern Part of the Red Sea, in particular from the three differently constituted areas, the Gulf of Suez, the Gulf of Aqaba and the Red Sea proper. The statistical constants were correlated with each other and with the contents of calcium carbonate, nitrogen and organic matter and these properties were correlated with the environmental conditions of deposition. Though sufficient work has not been done on the Red Sea deposits to enable general conclusions to be drawn, still conclusions relating to the effect of depth and the configuration of the sea-bottom seem to be well established. The irregular bottom topography gives rise to variety in the deposits. Contrasts appear between the deposits of the shallow and smooth Gulf of Suez, of the deeper Gulf of Aqaba, and the very irregular Red Sea proper.

INTRODUCTION

The following paper is an investigation of the mechanical analysis of some bottom samples collected during the Egyptian Preliminary Expedition to the Northern Red Sea in the R.RS. "Mabahith" in 1934–1935, when the senior author accompanied the expedition (2, 3 and 10). The mineralogy of the sediments is given in the succeeding article of this *Journal*. Sixty four samples were examined, of which fourteen are cores and fifty are grab samples. The localities of the different sampling stations are given in a previous publication (3, table p. 77), and their distribution is also shown in figure 1 (see also track chart and position of various sections in 3, figure 1, p. 6 and 10, figure 1, p. 308).[a] In table 1, the number of samples and the corresponding sections examined are given.

Core samples were collected by a Bigelow sounding rod whereas the grab samples were collected by a modified type of a Petersen grab.

To the author's knowledge, samples collected during previous expeditions to the Red Sea, such as the "Pola," the Magnaghi and the John Murray Expeditions[b] (15, 16 and 17), were not subjected

TABLE 1

Section examined	No. of samples
Gulf of Suez	3 core samples.
Gulf of Aqaba	7 grab samples.
Ghardaqa-Shadwan-Senafir	3 core samples and 31 grab samples.
Yuba-Mersa Daba	1 core sample and 2 grab samples.
Safaga-Mowila	3 core samples and 3 grab samples.
Qoseir-Brothers-No'man	4 core samples and 2 grab samples.
Daedalus-Hanak	5 grab samples.

[a] Also 20 charts and 5 sheets with echo sections published in connection with an article on bottom topography (1). Unfortunately these charts though published were never issued but could be obtained from the Librarian—Faculty of Science—Cairo.

[b] The observations of the John Murray Expedition as well as of the Dutch Snellius Expedition were restricted to but a few staions scattered over the southern part of the Red Sea.

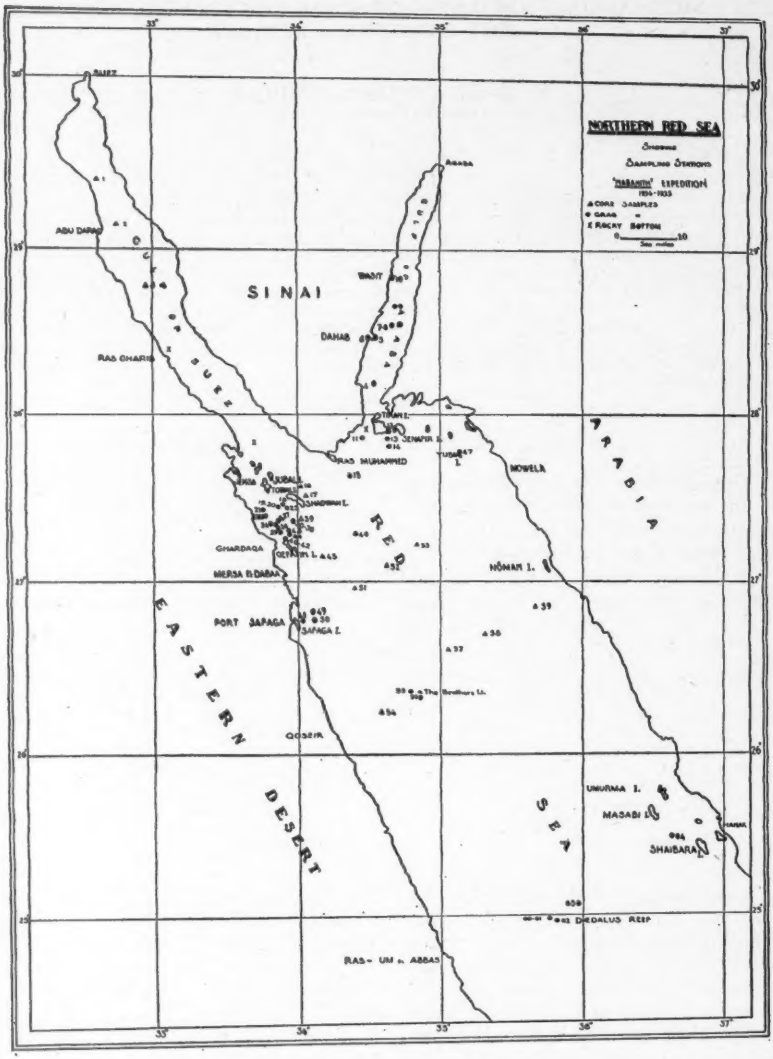

FIG. 1.—Northern Red Sea showing sampling stations.

TABLE 2. *Statistical constants of bottom sediments of Red Sea Northern Part.*

Section 1. Gulf of Suez.

No. of sample	University No.[1]	Station No.	Type of sample	Position		Depth in mts. (Echo)	Q_1 (mm)	Md (mm)	Q_3 (mm)	So	log So	Sk	log Sk	$CaCO_3$[2] %	Nitrogen %	Organic C %	Remarks
				Latitude N.	Longitude E.												
1	8503	1	Core—Top	29° 23′ 30″	32° 37′ 00″	62	.178	.044	.011	4.02	.604	1.01	.004	60.77	.050	.35	Marked increase of temp. and transparency.
			" —Bottom	"	"	"	.063	.017	.007	2.92	.465	1.61	.207				
2	8504	2	Core—Top	29 08 15	32 45 30	59	.072	.020	.006	3.42	.534	1.12	.049				Decrease of salinity in passing down Gulf of Suez.
			" —Middle	"	"	"	.043	.015	.004	3.20	.505	0.80	$\bar{1}$.903	57.27	.055	.45	
			" —Bottom	"	"	"	.074	.023	.008	3.00	.477	1.15	.061				
3	8505	3	Core—Top	28 46 45	32 57 15	64	.180	.064	.015	3.46	.539	0.66	$\bar{1}$.819				
			" —Middle	"	"	"	.200	.060	.010	4.58	.661	0.53	$\bar{1}$.723	73.02	.049	.38	
			" —Bottom	"	"	"	.115	.040	.012	3.16	.500	0.83	$\bar{1}$.919				
Section 2. Gulf of Aqaba.																	
4	8506	57	Grab	28 11 54	34 32 12	1128	.045	.010	.002	4.33	.637	1.20	.079	71.11	.033	.15	
5	8507	48	"	28 27 42	34 32 00	365	.060	.034	.015	2.00	.301	0.78	$\bar{1}$.892	77.20	.024	.06	Wire soundings excessive over echo as grab fell down slope. Echo (given in table probably too low owing to slope.
6	8508	49	"	28 27 24	34 30 18	265	.460	.200	.082	2.37	.375	0.95	$\bar{1}$.975				
7	8509	52b	"	28 32 00 / 28 32 18	34 40 12 / 34 40 06	1113–1143	.067	.018	.004	3.99	.601	0.87	$\bar{1}$.940	42.20	.023	.08	
8	8510	"	"	28 32 00 / 28 32 18	34 40 12 / 34 40 06	"	.080	.030	.008	3.14	.497	0.72	$\bar{1}$.857				
9	8511	54	"	28 40 30 / 28 38 30	34 42 18 / 34 41 18	1161–1393	.038	.014	.002	3.98	.600	0.47	$\bar{1}$.668	58.62	.024	.11	
10	8512	55	"	28 49 12	34 39 12	442	.014	.005	.002	2.52	.401	1.23	.090	57.65	.025	2.1	
Section 3. Ghardaqa-Shadwan-Senafir.																	
11	8513	43	Grab	27 52 00	34 27 24	1147	.048	.018	.003	3.70	.568	.47	1.676	76.52	.041	.21	
12	8514	41a	"	27 54 57	34 37 38	24	.450	.260	.180	1.58	.199	1.20	.079	95.17	.044	.09	
13	8515	58	"	27 51 30 / 27 52 00	34 38 12 / 34 38 00	596–616	.057	.022	.007	2.88	.459	.81	1.910	78.47	.055	.20	Near Tiran Island.
14	8516	42	"	27 49 30 / 27 49 00	34 39 30 / 34 38 42	741	.042	.015	.007	2.45	.389	1.31	.117	77.13	.032	.12	
15	8517	45a	"	27 29 30 / 27 38 00	34 23 30 / 34 22 36	960	.055	.200	.013	2.06	.314	1.79	.253	75.21	.016	.09	Near Ras Mohamed.
16	8518	40	Core—Top	27 34 36	34 00 51	941	.051	.022	.010	2.26	.354	1.03	.013				
			" —Middle	"	"		.040	.019	.007	2.39	.378	.77	$\bar{1}$.890	80.32	.086	.22	
			" —Bottom	"	"		.038	.018	.007	2.35	.371	.81	$\bar{1}$.908				
17	8519	7	Core—Top	27 30 40 / 27 29 36	34 03 30 / 34 05 10	731	.066	.029	.009	2.70	.431	.70	$\bar{1}$.848				East of Shadwan Island.
			" —Middle	"	"		.060	.031	.012	2.24	.350	.75	$\bar{1}$.875	81.27	.049	.31	
			" —Bottom	"	"		.064	.038	.018	1.88	.274	.75	$\bar{1}$.875				

TABLE 2. (*continued*)

Section 3. Ghardaqa-Shadwan-Senafir (continued)

No. of sample	University No.[1]	Station No.	Type of sample	Position		Depth in mts. (Echo)	Q_1 (mm)	Md (mm)	Q_3 (mm)	So	log So	Sk	log Sk	$CaCO_3$ %	Nitrogen %	Organic C %	Remarks
				Latitude N.	Longitude E.												
18	8520	26	Grab	27 27 48	33 54 18	236	.320	.200	.085	1.94	.288	.68	$\bar{1}$.832	83.62	.041	.11	
19	8521	32a	"	Round		30–102											
				27 17	33 52 06	(wire)	1.400	.640	.220	2.52	.401	.75	$\bar{1}$.878	89.09	.058	.24	
20	8522	32c	"	"	"	"	1.440	.710	.310	2.16	.334	.89	$\bar{1}$.948				
21	8523	21a	"	27 26 42	33 45 33	73	.078	.035	.015	2.28	.358	.95	$\bar{1}$.980	84.70	.091	.35	
22	8524	20j	"	27 21 51	33 46 30	17–21	1.38	.57	.27	2.26	.354	1.14	.059				
23	8525	20c	"	"	"	"	"	"	"	"	"	"	"	96.96	.029	.19	
24	8526	15a	"	27 20 48	33 47 48	20–53	1.82	.780	.36	2.25	.352	1.08	.033				
				27 20 30	33 48 03	(wire)											
25	8527	27	"	27 27 48	33 54 00	203	.74	.34	.20	1.93	.286	1.28	.107				
26	8528	14a	"	27 19 39	33 48 06	66–70	.80	.37	.21	1.95	.290	1.22	.088	92.26	.029	.13	
				27 19 30	33 48 24	(wire)											
27	8529	14c	"	"	"	"	1.10	.50	.30	1.91	.282	1.32	.121				
28	8530	18a	"	27 19 18	33 48 48	66–71	.132	.035	.021	2.51	.400	2.26	.354	91.28	.042	.15	
						(wire)											
29	8531	19	"	27 17 54	33 50 12	102	.14	.059	.025	2.36	.373	1.01	.002	88.33	.052	.39	
						(wire)											
30	8532	34h	"	27 23 24	33 56 30	80–433	.42	.240	.14	1.73	.238	1.02	.009	92.53	.024	.09	
				27 24 21	33 55 48												Between Ghardaqa and Shadwan Island.
31	8533	34	Grab 9	"	"	"	.42	.290	.20	1.45	.161	1.00	.000				
32	8534	34c	"	"	"	"	.94	.580	.33	1.69	.227	.92	$\bar{1}$.965				
33	8535	34a	"	"	"	"	.70	.320	.18	1.97	.294	1.23	.090	94.86	.030	.11	
34	8536	34	Grab 12	"	"	"	.56	.320	.21	1.63	.212	1.15	.061				
35	8537	34b	"	"	"	"	.50	.270	.18	1.66	.221	1.23	.092				
36	8538	34L	"	"	"	"	.080	.034	.014	2.39	.378	.97	$\bar{1}$.987	81.66	.072	.30	
37	8539	34	Grab 5	"	"	"	1.00	.550	.30	1.82	.261	.99	$\bar{1}$.996				
38	8540	34	Grab 8	"	"	"	.40	.220	.13	1.75	.244	1.07	.031				
39	8541	37	Core—Top	27 24 48	33 59 15	366	.052	.024	.010	2.30	.362	.89	$\bar{1}$.948	80.52	.039	.19	
				27 24 42	34 00 00												
			" —Bottom	"	"	"	.041	.018	.005	2.78	.444	.67	$\bar{1}$.826				
40	8542	22b	Grab	27 16 00	33 51 54	89	.065	.031	.011	2.38	.377	.95	$\bar{1}$.978				
41	8543	22c	"	27 16 24	33 51 18	102	.062	.028	.012	2.28	.358	.95	$\bar{1}$.978	88.14	.082	.38	
42	8544	22a	"	27 16 12	33 51 24	102	.056	.025	.015	1.93	.287	1.34	.127				
43	8545	23c	"	27 18 24	33 52 36	93	.55	.300	.195	1.68	.225	1.19	.075	95.43	.025	.11	
				Round													
44	8546	33	"	27 17	33 52 06	22–51	.18	.085	.03	2.45	.389	.75	1.873				

Section 4. Yuba-Mersa Daba'

45	8547	67	Core—Top	27 08 42	34 10 00	814	.060	.027	.014	2.07	.316	1.15	.061	75.77	.031	.18	
				27 07 00	34 10 45												
			" —Middle	"	"	"	.090	.027	.014	2.53	.403	1.73	.238				
			" —Bottom	"	"	"	.070	.025	.010	2.64	.421	2.80	.447				
46	8548	66	Grab	27 19 00	34 26 30	1079–	—	.080	.014	—	—	—	—	—	—	—	Ships' clinkers present.
				27 17 15	34 21 00	1225											
47	8549	62	"	27 46 30	35 09 00	247–	.050	.020	.008	2.53	.403	.92	$\bar{1}$.989				
				27 46 42	35 08 00	336											

Section 5. Safaga-Mowila.

48	8550	75	Grab	27	03	18	34	12	24	468–486	.120	.050	.020	2.45	.389	.96	$\bar{1}$.982				Near Safaga Island.
49	8551	69	"		"			"		92–400	1.440	.380	.160	3.00	.477	1.59	.201				Panorama Reef.
50	8552	74	"		"			"		—	.250	.170	.130	1.39	.143	1.12	.051				
51	8553	76	Core—Top	26	57	36	34	23	36	951	.045	.011	.005	2.94	.468	1.93	.285				
			" —Middle	26	57	12	34	23	30	"	.060	.014	.006	3.22	.508	1.77	.249	69.45	.030	.15	
			" —Bottom		"			"			.040	.012	.002	4.08	.611	.66	$\bar{1}$.823				
52	8554	77	" —Top	27	05	24	34	37	00	1274	.015	.005	.002	2.61	.416	1.27	.104				
				27	04	54	34	37	09												
			" —Middle		"			"			.015	.014	.005	1.77	.248	2.38	.376	78.27	.023	.13	
			" —Bottom		"			"			.046	.025	.007	2.53	.403	.53	$\bar{1}$.724				
53	8555	78	" —Top	27	13	21	34	50	12	1148	.150	.024	.011	3.69	.567	2.82	.450				
				27	12	30	34	50	30												
			" —Middle		"			"			.054	.019	.006	3.00	.477	.85	$\bar{1}$.929	77.52	.019	.11	
			" —Bottom		"			"			.080	.020	.004	4.59	.662	.76	$\bar{1}$.881				

Section 6. Qoseir-Brothers'-No'man.

54	8556	86	Core—Top	26	13	15	34	36	12	667	.051	.012	.006	2.80	.447	2.30	.362				
			" —Middle		"			"			.048	.013	.003	3.94	.595	.88	$\bar{1}$.944	78.72	.024	.13	Between Egyptian coast and Brothers'.
			" —Bottom		"			"			.052	.025	.007	2.64	.422	.62	$\bar{1}$.795				
55	8557	88	Grab	On slopes of Brothers' Islets.						90–940	1.58	.760	.47	1.83	.262	1.29	.111				Grab generally failed to close.
56	8558	87a	"		"					84–198	.95	.51	.37	1.60	.204	1.35	.130				Near Brothers' Island.
57	8559	83	Core—Top	26	34	33	35	03	45	1234	.050	.011	.004	3.63	.560	1.57	.196				
				26	33	30	35	03	06												
			" —Middle		"			"			.032	.011	.005	2.61	.417	1.24	.095	58.82	.047	.29	
			" —Bottom		"			"			.050	.018	.005	3.10	.491	.80	$\bar{1}$.906				
58	8560	82a	" —Top	26	38	00	35	21	30	834	.115	.011	.004	5.65	.752	3.42	.534				
			" —Middle		"			"			.050	.012	.004	3.49	.543	1.42	.154	80.87	.018	.11	Between Brothers' and Arabian coast.
			" —Bottom		"			"			.044	.015	.002	4.47	.650	.43	$\bar{1}$.633				
59	8561	81b	" —Top	26	48	30	35	40	36	873	.048	.017	.007	2.62	.418	1.16	.065				
				26	50	30	35	41	30												
			" —Middle		"			"			.12	.025	.007	4.00	.602	1.44	1.58	72.49	.028	.15	
			" —Bottom		"			"			.036	.012	.004	3.00	.477	1.00	.000				

Section 7. Daedalus-Hanak

60	8562	102c	Grab	24	55	15	35	51	27	183	1.38	.82	.50	1.66	.220	1.02	.011				
61	8563	102	Grab 3		"			"		466	1.20	.75	.50	1.55	.190	1.07	.029				Near Daedalus Reef.
62	8564	103	"	24	55	20	35	51	00	512	.33	.28	.20	1.28	.107	.842	$\bar{1}$.925				
63	8565	98	"	25	01	00	36	01	00	1214	.18	.029	.022	2.86	.456	4.71	.673	—	—	—	"Mabahith" Deep.
				25	02	48	36	00	30												
64	8566	91	"	25	25	00	36	40	00	19–25	.38	.22	.16	1.54	.187	1.26	.100				

[1] Numbers refer to specimens housed in the Geological Museum, Fouad I. University, Cairo.
[2] After A. F. Mohamed (9).

to mechanical analyses and, with the exception of Sujkowski's work (12) on a few samples collected by S. S. Endeavour from the southern part of the Sea, nothing is known about the mineralogy of the bottom deposits. A. F. Mohamed examined the chemistry of some of the bottom samples collected during the present expedition (10, p. 314 and 9) and he concluded that the environmental conditions of deposition are, on the whole, different in each of the three main regions investigated, namely the Gulf of Suez, the Gulf of Aqaba and the northern part of the Red Sea proper.

The Gulfs of Suez and Aqaba differ greatly, the former having a flat bottom at a depth of 36–72 meters, whereas the latter has a trough 1600–1800 meters (900–1000 fms.) deep over to its eastern side, and its bottom is irregular even at the greatest depth. The Gulf of Aqaba, only about 22 kms. wide, has a depth nearly equal to the greatest depth of the Red Sea, which is about ten times as broad. The Red Sea itself is deeper in proportion to breadth than any other. The maritime plain so characteristic of the Red Sea shores, where it is generally up to 32 kms. wide, is almost absent on the Gulf of Aqaba where the shores are extremely abrupt and the mountains on its sides rise sheer from the water. The descent to the greatest depths in the Red Sea proper is by a series of steps, except in places on the Arabian side, where there are abrupt falls to 720–900 meters. Another character of the topography of the Red Sea bottom is the presence of small isolated reefs rising abruptly from deep water and lying on foundation rocks. The most conspicuous are the Brothers' Islets, rising from 1080 meters (11) and Daedalus Reefs located not far from the middle of the sea. Other ridges do not reach the surface but form submarine hills and mountains giving the bottom a very irregular topography[e] (1 and 2, Figs. 1 & 2) Such variation in topography has a great influence on the mechanical composition of the bottom deposits.

[e] The charts and sections published in connection with this reference were not issued as previously mentioned.

TECHNIQUE USED IN THE LABORATORY

The samples examined were divided into two divisions, those containing 95% or more of material coarser than 84.7μ and a second division containing samples with more than 5% of material finer than 84.7μ. The samples of the first division were analyzed by sieving methods. They were quartered and about 25 to 30 g. were screened through a set of sieves (meshes Nos. 10, 30, 60, 120, and 200 with openings of 2001, 610.2, 271.1, 135.6 and 84.7 microns in diameter as calibrated microscopically), using a mechanical shaker for fifteen minutes. Both sieving and sedimentation methods were used for sediments of the second division. In this case about 40 g. of each sample were thoroughly deflocculated using the technique suggested by Krumbein (7 and 8, pp. 51 ff.). Experiments were made to choose a suitable procedure for effectively dispersing the samples. For this reason 0.5 g. of a representative sample was put into each of a set of test tubes which were subsequently filled with the following peptizers:—N/25, N/50 and N/100 sodium carbonate, dilute ammonia (400 ml. distilled water added to 40 ml. of freshly prepared 33% ammonia solution), N/100 sodium oxalate, sodium silicate (0.5 ml. of N/5 sodium silicate in 500 ml. distilled water), N sodium hydroxide, N ammonium carbonates and boiling N ammonium carbonate plus a few drops of sodium hydroxide solution. The suspensions were subsequently well stirred and left overnight. The same experiments were made after washing the samples free from electrolytes as confirmed by the addition of silver nitrate to the filtrate. None of the unwashed samples were deflocculated. On the other hand, all the samples free from electrolytes were at least partially dispersed. Examining a few drops of each suspension under the microscope, it was concluded that the

dilute ammonia solution is the most suitable peptizer. A mechanical stirrer was used for ten minutes to complete the dispersion.

After thorough dispersion the pipette method as described by Krumbein (6 and 8, pp. 166 ff.) was used for mechanical analysis. Suspension was sucked by the pipette at intervals corresponding to the following grain sizes in microns: 84.7–31.2, 31.2–15.6, 15.6–7.8, 7.8–3.9, 3.9–1.95, 1.95–0.98. In both coarser and finer sediments the weight percentages of the different fractions (corresponding with the different meshes used or with the different readings of the pipette) were determined. The data obtained were then represented on cumulative logarithmic curves. The median diameter Md, the coefficient of sorting So and its logarithm log So, and the coefficient of skewness Sk and its logarithm log Sk (8, pp. 229 ff.) were calculated from the cumulative curves. The weight percentages of the grain sizes corresponding with the Wenworth scale (8, p. 80) were also calculated from the cumulative curves and the corresponding histograms were drawn.

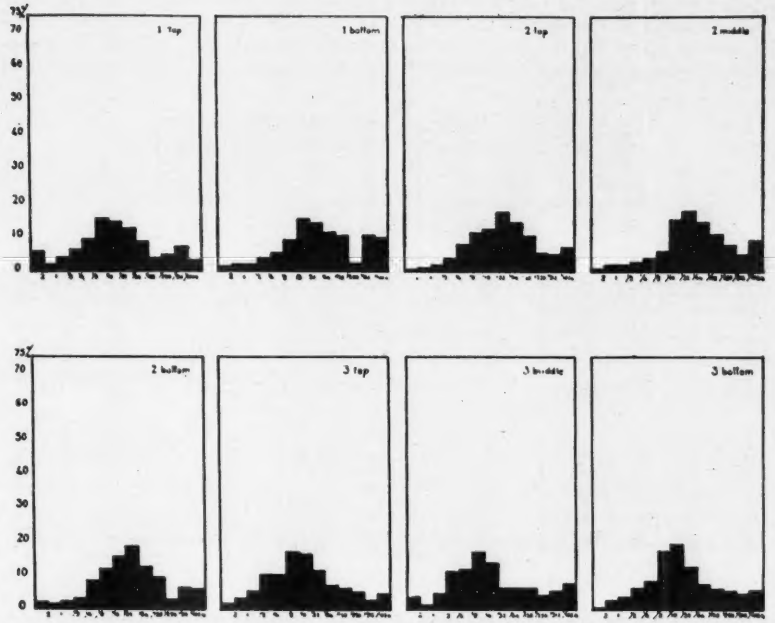

FIG. 2.—Histograms of section 1 of sediments of Gulf of Suez. Vertical components represent percentage from 0 at the bottom to 75 at the top; horizontal components shown at the bottom of each diagram range from 4 mm. at the extreme left to 1/2048 at the extreme right.

DISCUSSION OF RESULTS

1. *Gulf of Suez*

Section 1 of Table No. 2 includes the statistical constants of the three cores collected from the Gulf of Suez, (six, nine and fourteen kms. away from its western shore and from about the same depth,

ranging from 59 to 64 meters) and their corresponding histograms and cumulative curves are given in figures 2 and 3. Inspection of table 2 shows that the median diameters of the sediments range between 15 and 64 μ. There is a decrease from top to bottom in cores 1 and 3, a relation which does not hold for core 2. The sediments of this section are normally sorted (13, p. 62), with a coefficient of sorting ranging between 2.92 and 4.02, with the exception of the middle portion of core No. 3 which is a poorly sorted sediment with So = 4.58. The average sorting factor of each of the three cores varies slightly (3.47—3.20—3.73). This might be attributed to their approximate equal depths, to the identity in the configuration of the flat bottom, and to the fact that no samples were collected from the shore[d].

Skewness is very small in some parts of the cores, whereas, in others it tends towards either the finer or the coarser fractions. These data are comparable with those given by other normally sorted sediments from continental shelves; the Gulf of Suez is itself a shallow flat shelf filled with the surface water of the Red Sea and descending at its mouth abruptly to a depth five times greater than its own. The smoothness of the bottom of the gulf explains in part the mild changes in the physical constants of its bottom sediments. Further discussion of the interrelations of the properties of the sediments of the Gulf of Suez and of these properties with environmental conditions of deposition are referred to later.

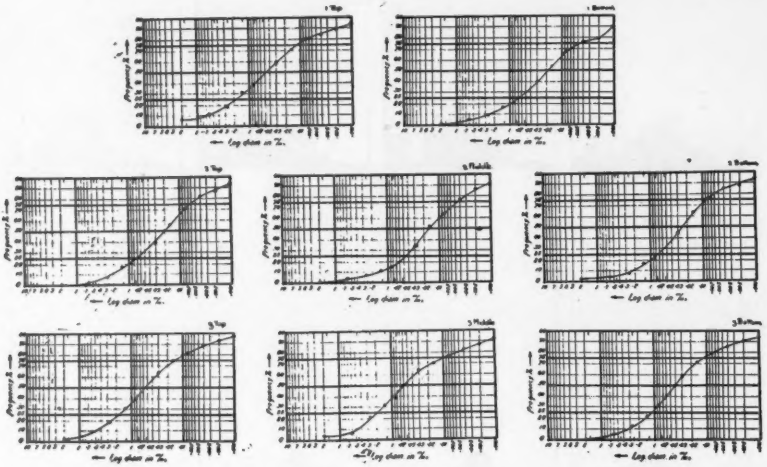

FIG. 3.—Cumulative curves of section 1 sediments of Gulf of Suez. Frequencies are shown on the left in percentages ranging from 0 at the base to 100 at the top. Along the bottom are shown values of the log. diam. in m/ms.

2. *Gulf of Aqaba*

Section 2 of table 2 gives the statistical constants of the seven grab samples collected from the Gulf of Aqaba. The samples were secured from deeper waters (ranging between 265–1393 meters) than those of the Gulf of Suez. Three grab

[d] Fifteen samples were kindly provided to the authors by Dr. H. A. F. Gohar from the shore between Suez and Ghardaqa. They were found to be well sorted and were comparable with other beach deposits described in the literature.

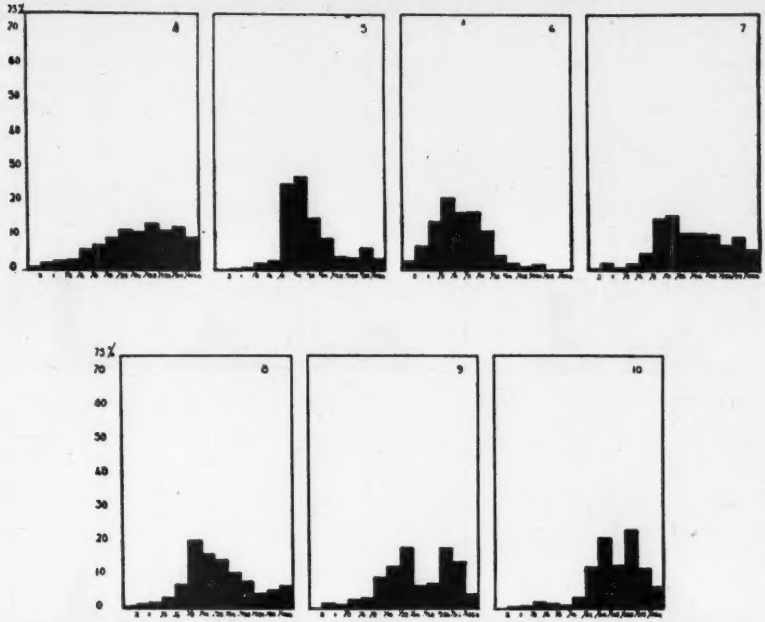

FIG. 4.—Histograms of section 2 sediments of Gulf of Aqaba. Vertical components represent percentage from 0 at the bottom to 75 at the top; horizontal components shown at the bottom of each diagram range from 4 mm. at the extreme left to 1/2048 at the extreme right.

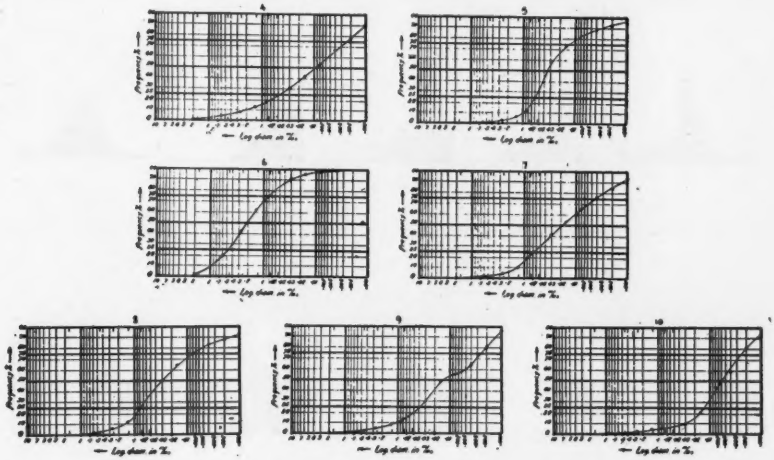

FIG. 5.—Cumulative curves of section 2 sediments of Gulf of Aqaba. Frequencies are shown on the left in percentages ranging from 0 at the base to 100 at the top. Along the bottom are shown values of the log. diam. in m/ms.

samples (5, 6 and 10) are nearer to shore than others located nearer to the mid-sea and from deeper waters. Figures 4 and 5 give the histograms and cumulative curves of the Gulf of Aqaba sediments. In contradistinction with the Gulf of

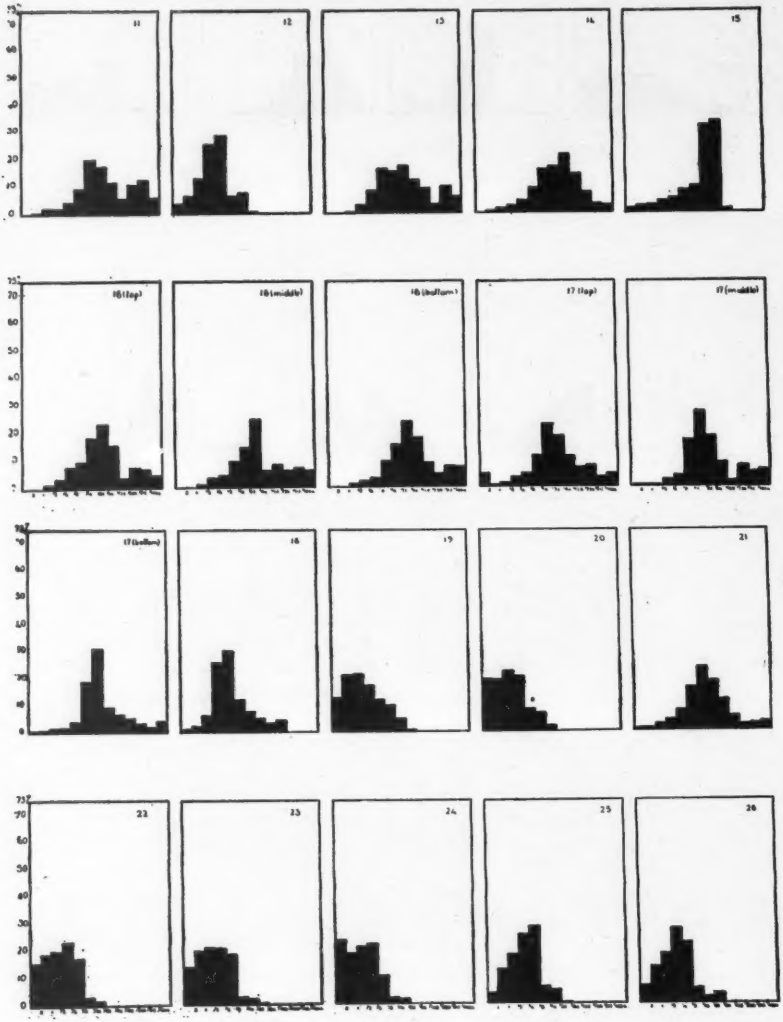

FIG. 6.—(Continued on next page)

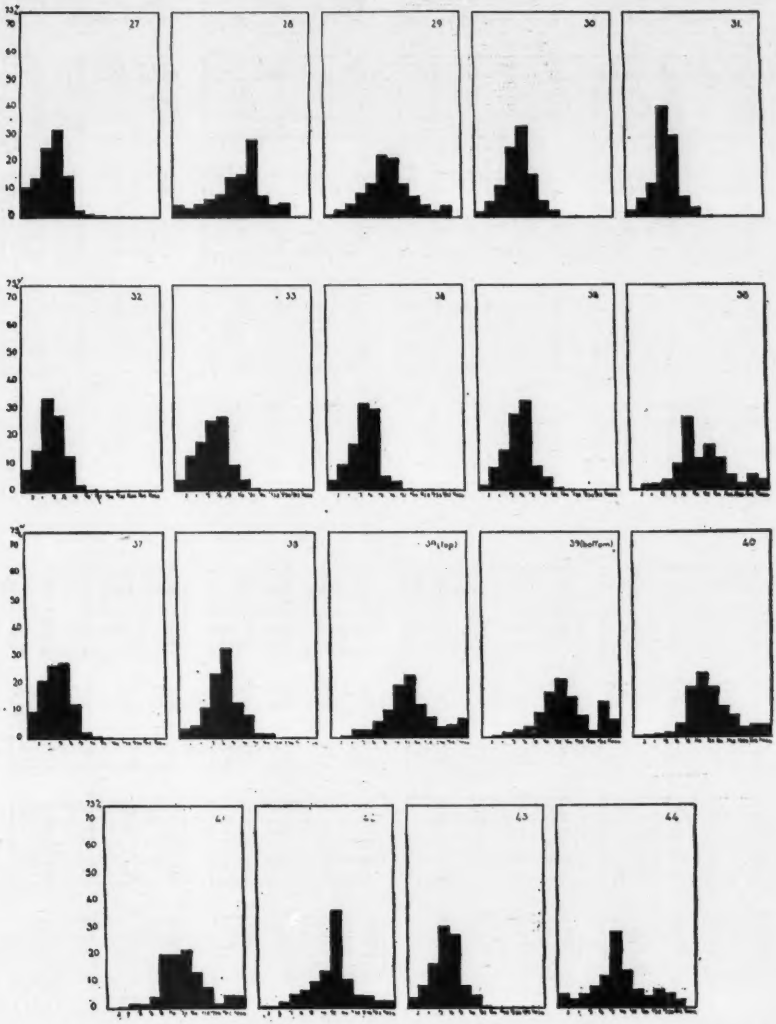

FIG. 6.—Histograms of section 3 sediments of Ghardaqa-Shadwan-Senafir. Vertical components represent percentage from 0 at the bottom to 75 at the top; horizontal components shown at the bottom of each diagram range from 4 mm. at the extreme left to 1/2048 at the extreme right.

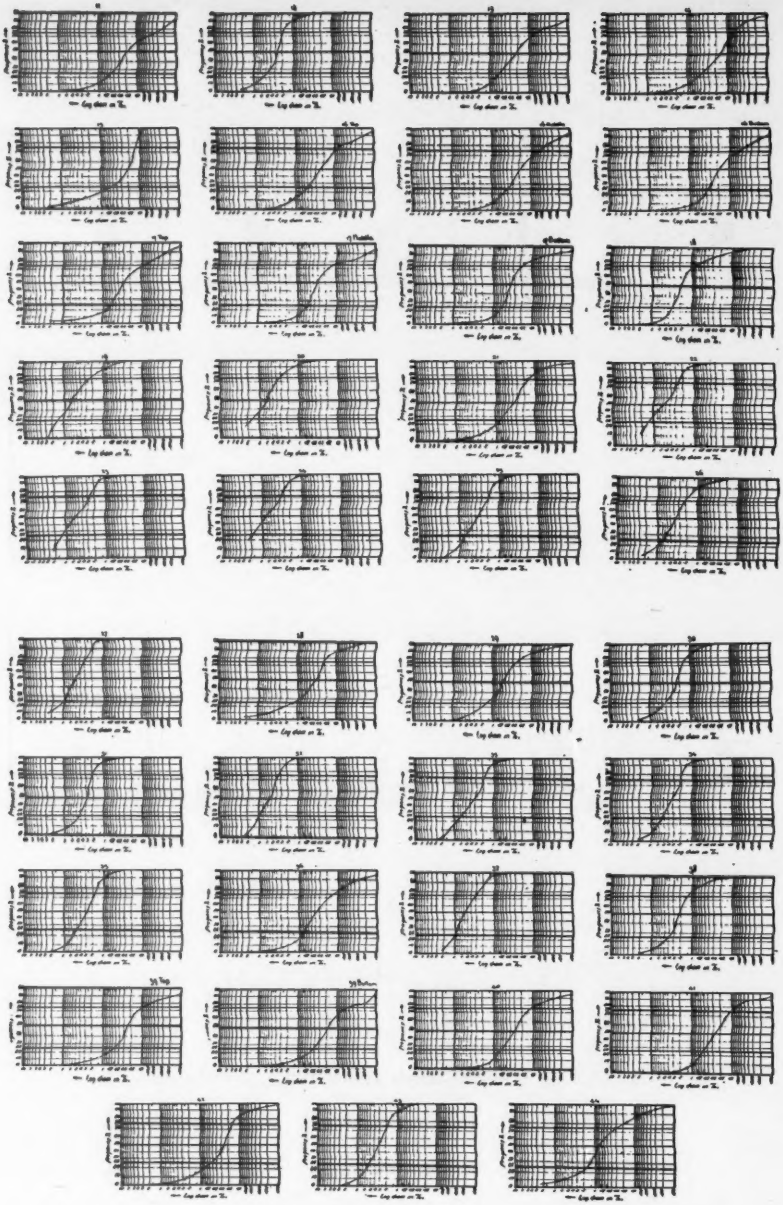

FIG. 7.—Cumulative curves of section 3 sediments of Ghardaqa-Shadwan-Senafir. Frequencies are shown on the left in percentages ranging from 0 at the base to 100 at the top. Along the bottom are shown values of the log. diam. in m/ms.

Suez samples the median diameters of the Gulf of Aqaba samples vary greatly, ranging from .005–.200 mm. The samples are either well sorted or normally sorted, the sorting factor ranging between 2.00 and 4.33. It is to be noted here that the well sorted samples are those collected from the shallower and nearer shore stations, off Dahab and Wasit. It is also of interest to note that two of these well sorted sediments (5 and 6) collected outside Wasit are located on a slope, and have fractions of nearly the same size. Log of skewness of the samples varies between +.090 and −.332.

In contradistinction with the Gulf of Suez, variation of the statistical data of *the bottom sediments of the Gulf of* Aqaba is in harmony with the roughness and irregular *configuration of its bottom.*

3. *Ghardaqa—Shadwan—Senafir Section.*

Three core samples and 31 grab samples were examined from this most northern section of the Red Sea, from depths varying from 17–1147 meters. The samples include four, collected near Tiran and Senafir Islands at the entrance of the Gulf of Aqaba (11–14), one south of Ras Mohamed (15), two east of Shadwan Island (16–17) and the majority (18–44) between Shadwan Island and the Marine Biological Station of the Fouad I University at Ghardaqa (Hurghada). Their statistical constants and other properties are given in section 3 of table 2, and the corresponding histograms and cumulative curves are shown in figures 6 and 7.

The median diameters range between .015–.780 mm. Those of the samples collected from the entrance of the Gulf of Aqaba are small (.015–0.22 mm.) and the sediments are normally sorted, except the single sample collected from the shallow waters nearer to the shores of Tiran Island (12) which possesses a greater median (0.260 mm.) and is better sorted than the others (So = 1.58). The samples collected south of Ras Mohamed and east of Shadwan possess small medians (.018–.038 mm.) and are all from relatively deep waters. The median diameter of the remaining sediments between Shadwan and Ghardaqa varies greatly, ranging between .018–.780 mm. and sediments are mostly well sorted with but few possessing a sorting coefficient slightly greater than 2.5, the upper limit of well sorted sediments (sorting coefficient varying between 1.45–2.78). Log of skewness varies from zero to 1.989, all being either symmetrical or asymmetrical in a positive sense.

The fact that the statistical constants depend on the configuration of the sea bottom is beautifully illustrated by the samples collected at station 34, which lies over a submarine hill discovered by the present Expedition west of Shadwan Island. All samples (31–88) lie on the slopes of the hill except one sample (36) located at its foot. The sample from the base possesses the smallest median diameter and is not as well sorted as the other samples. The median diameter varies widely in samples collected between Shadwan Island and Ghardaqa; the irregularity of the bottom, with submarine hills and slopes, in the area is in harmony with this variation in mechanical constitution (see 4, fig. 2, p. 26, showing reefs and shoals of area and 2, fig. 1 showing Section between Shadwan and Ghardaqa).

4. *Yuba—Mersa Daba' Section*

Section 4 of table 2 gives the statistical constants of the single core and two grab samples analyzed, whereas figures 8 and 9 give the corresponding histograms and cumulative curves. The samples were secured from comparatively deep waters ranging between 247 and 1225 meters and far from the mainland, except one (47) which was collected not far from the northern end of Yuba Island. They are fine grained sediments with median diameters varying from .020–.080 mm. One sample is very poorly sorted owing to the presence of ships' clinkers in the coarser fractions; the sample being secured from underneath the main route of ships crossing the Red Sea; the two others are on the border line between well sorted and

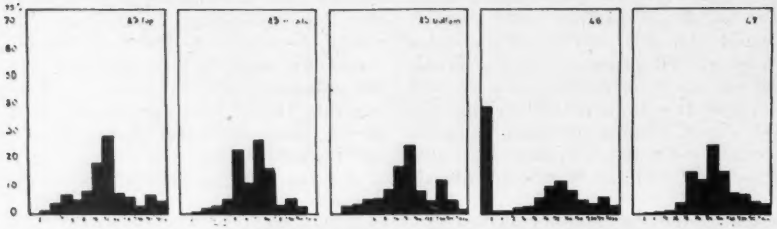

FIG. 8.—Histograms of section 4 sediments of Yuba-Mersa Daba'. Vertical components represent percentage from 0 at the bottom to 75 at the top; horizontal components shown at the bottom of each diagram range from 4 mm. at the extreme left to 1/2048 at the extreme right.

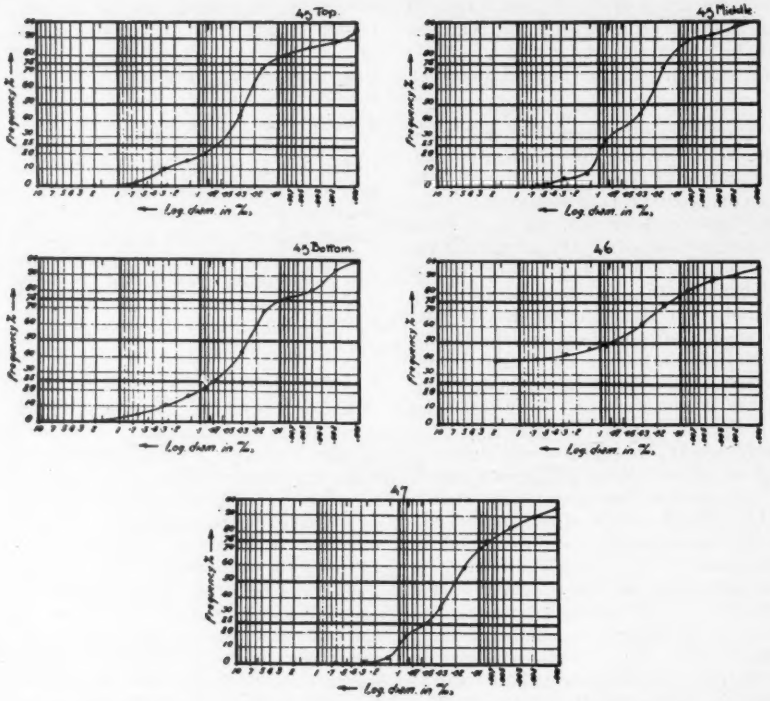

FIG. 9.—Cumulative curves of section 4 sediments of Yuba-Mersa Daba'. Frequencies are shown on the left in percentages ranging from 0 at the base to 100 at the top. Along the bottom are shown values of the log. diam. in m/ms.

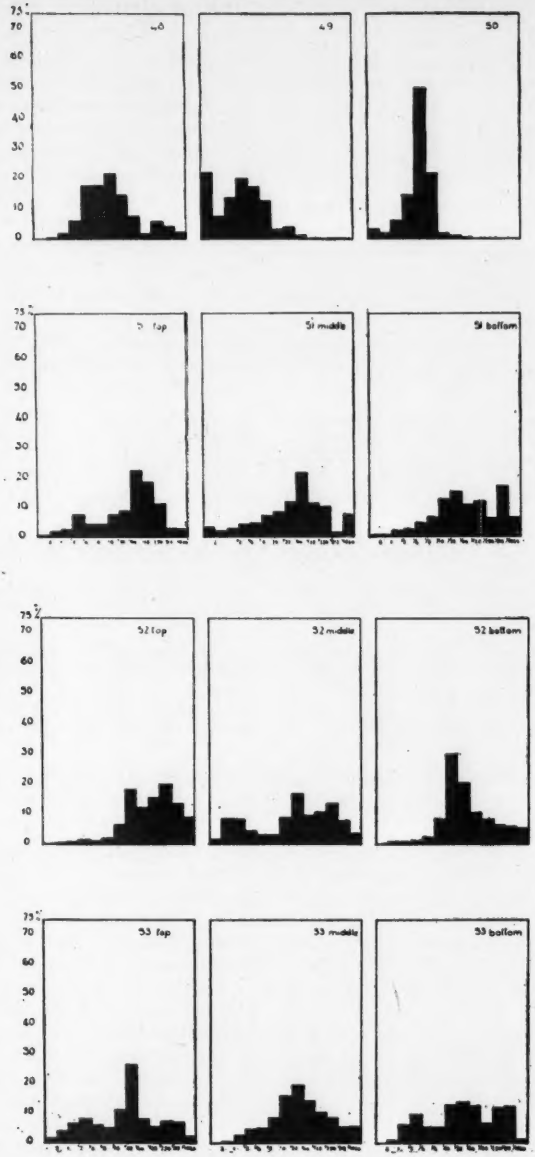

FIG. 10.—Histogram of section 5 sediments of Safaga-Mowila. Vertical components represent percentage from 0 at the bottom to 75 at the top; horizontal components shown at the bottom of each diagram range from 4 mm. at the extreme left to 1/2048 at the extreme right.

normally sorted sediments. The log of skewness of the samples varies between .975 and 2.80.

5. *Safaga—Mowila Section*

Three grab samples and three cores were examined from this section. They spread from east of Safaga Island to near the middle of the sea with no samples from the Arabian side. Their statistical constants are given in section 5 in table 2 and the corresponding histograms and cumulative curves are shown in figures 10 and 11. The samples were collected from relatively deep waters (between 468–1274 meters) and are fine grained sediments with median diameters varying between .005–.050 mm. except for two samples collected from Panorama Reef, which are from shallower water and coarser in nature (with Md = .38 and .17 mm.). The sediments are either well sorted, normally sorted, or poorly sorted with sorting factor varying between 1.39 and 4.59. The asymmetry of the sediments is either towards the coarser or finer fractions.

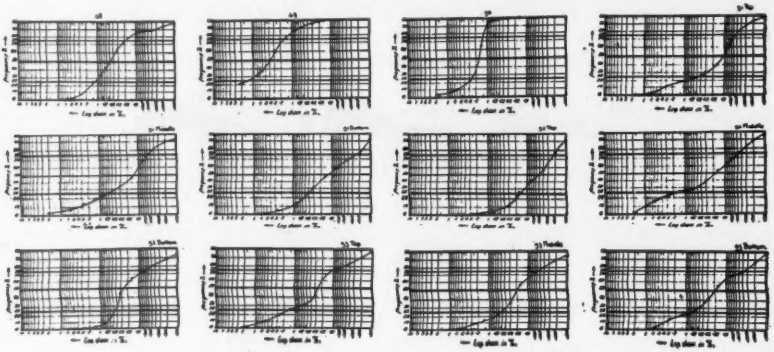

FIG. 11.—Cumulative curves of section 5 sediments of Safaga-Mowila. Frequencies are shown on the left in percentages ranging from 0 at the base to 100 at the top. Along the bottom are shown values of the log. diam. in m/ms.

6. *Qoseir—Brothers'—No'man Section.*

Four cores and two grab samples were analysed from this section, and were collected from depths varying between 84 and 1234 meters. Their statistical constants are given in section 6 of table 2 and the corresponding histograms and cumulative curves are shown in figures 12 and 13. As previously mentioned, the Red Sea floor is in its greater parts very irregular and the bottom of the present section is no exception. The two Brothers' Islets, for instance, which are formed of foundation crystalline rocks (or "continental blocks") and not by the accumulation of volcanic extrusions as is the case with the volcanic islets of the Pacific, form the summits of a submarine hill about 1000 meters high (11). This irregularity of the bottom is shown by the following notes recorded at some of the sampling stations: "irregular bottom, no catch," "grab generally failed to close," "grab closed upon, and damaged its wire, indicating steep irregular bottom." The samples collected from this section are distributed as follows: one sample from the bottom between the Egyptian coast and the Brothers' (no. 54), two from the slopes of the Brothers' (nos. 55–56) and three cores from between the Brothers' and the Arabian coast (nos. 57–59).

The median diameters of the samples of this section vary from .011–.025 mm. for the samples other than those collected

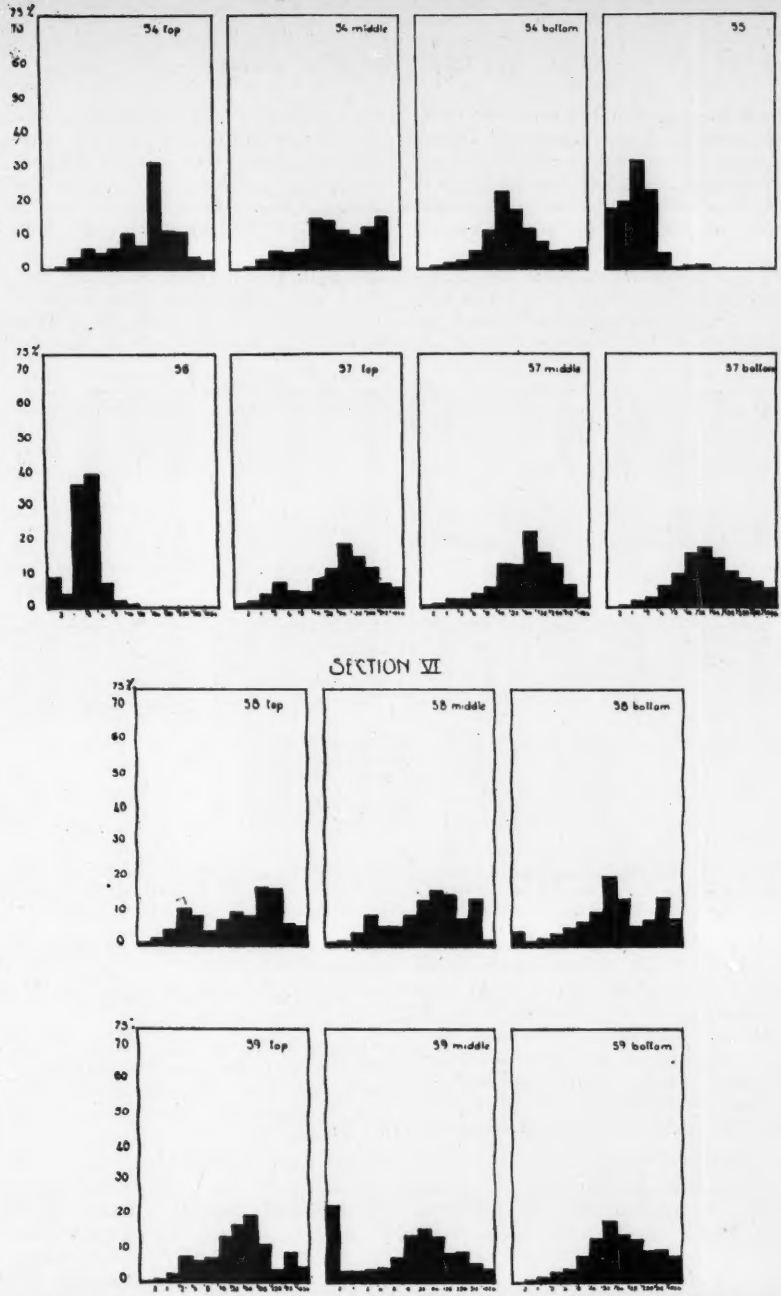

FIG. 12.—Histograms of section 6 sediments of Qoseir-Brothers'-No'man. Vertical components represent percentage from 0 at the bottom to 75 at the top; horizontal components shown at the bottom of each diagram range from 4 mm. at the extreme left to 1/2048 at the extreme right.

from the slopes of the Brothers' Islets, the medians of which are much coarser and vary from .760 to .510 mm. These two samples, collected from the slopes of the Brothers', are also well sorted (with So = 1.60 and 1.83) in contradistinction with the other samples which are normally or poorly sorted. This fact of the coarseness and well sorted nature of sediments collected from slopes is also beautifully shown by the samples of the sub-Masabi Reef, near the Arabian coast (no. 64). Section 7 of table 2 gives the statistical constants of these samples and their histograms and cumulative curves are shown in figures 14 and 15. The median diameters of the samples are relatively coarse and vary from .22–.82 mm. and are well sorted (with So = 1.28–1.66). They were collected from the slopes of Daedalus Reef and from the shallow waters near Masabi Reef, on the other

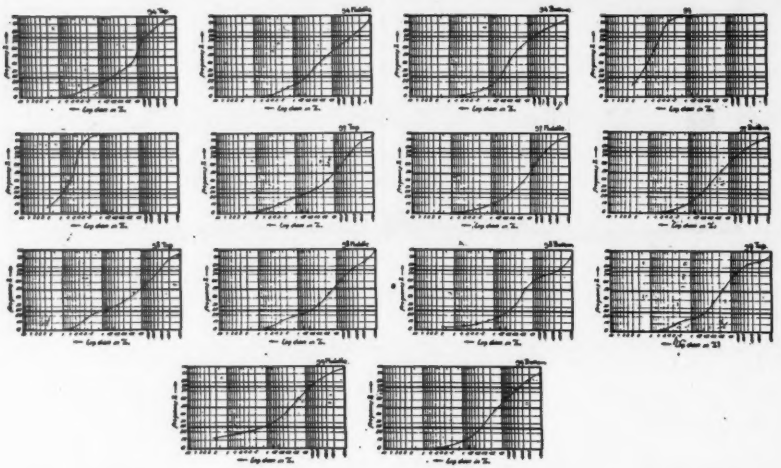

FIG. 13.—Cumulative curves of section 6 sediments of Qoseir-Brothers'-No'man. Frequencies are shown on the left in percentages ranging from 0 at the base to 100 at the top. Along the bottom are shown values of the log. diam. in m/ms.

marine hill west of Shadwan Island further north and by those on the slopes east of Wasit in the Gulf of Aqaba. Log of skewness of the samples changes in both positive and negative senses.

It is of interest to note here also that the great changes in the bottom topography are in harmony with changes in the statistical constants of the sediments.

7. *Daedalus—Hanak Section.*

Five samples were examined from this section: three from west of Daedalus (nos. 60–62), one from the "Mabahith" Deep lying between Daedalus Reef and the Arabian coast (no. 63) and one from hand the deep sample (no. 63) is much finer and less sorted.

INTERRELATION OF PROPERTIES OF THE SEDIMENTS

The following is a discussion of the interrelation of the properties of the sediments examined. The discussion shows that the properties are in many respects interdependent.

Median Diameter: Sorting:

In figure 16 the median diameter is plotted against the sorting factor for all the samples analyzed. It is clear from the graph that the trend of the line drawn indicates that the degree of sorting be-

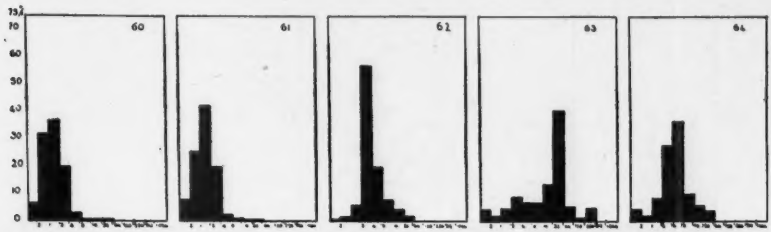

FIG. 14.—Histograms of section 7 sediments of Daedalus-Hanak. Vertical components represent percentage from 0 at the bottom to 75 at the top; horizontal components shown at the bottom of each diagram range from 5 mm. at the extreme right left to 1/2048 at the extreme right.

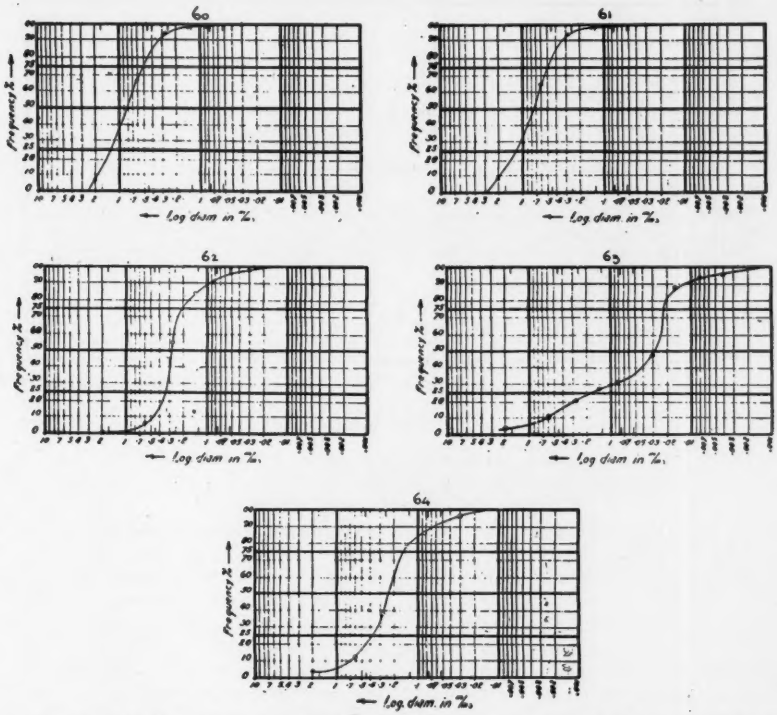

FIG. 15.—Cumulative curves of section 7 sediments of Daedalus-Hanak. Frequencies are shown on the left in percentages ranging from 0 at the base to 100 at the top. Along the bottom are shown values of the log. diam. in m/ms.

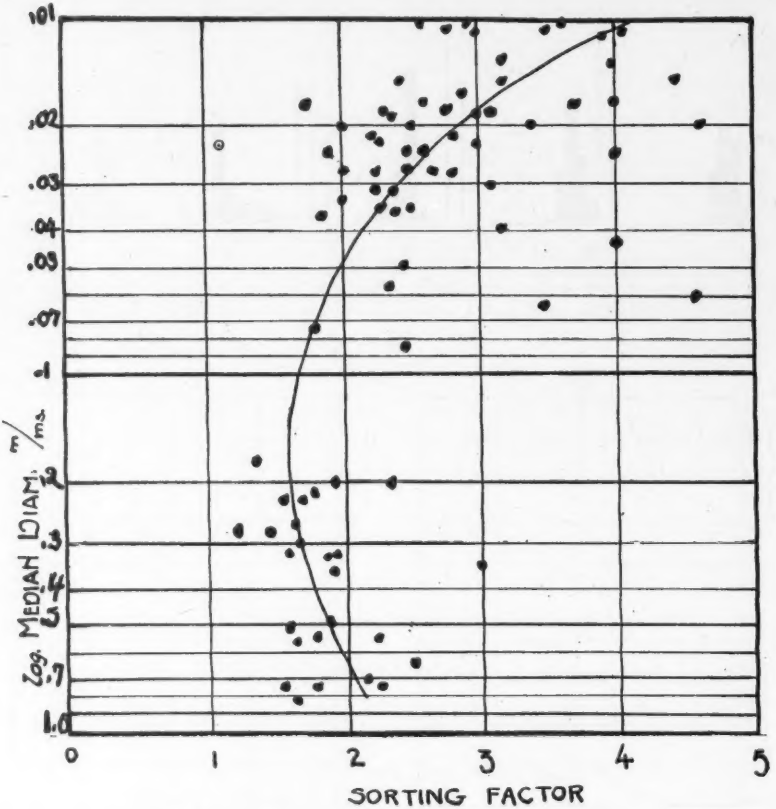

FIG. 16.—Relation between median diameter and sorting factor of Northern Red Sea sediments.

comes slightly better from the larger median diameters (about 1 mm.) down to about 0.15 mm., then becomes poorer as the diameter decreases to .009 mm. It is of interest to notice that a similar relation was recorded by Hough for the sediments of Cape Cod Bay and Buzzards Bay, Massachusetts (5, p. 19), notwithstanding the fact that the Red Sea sediments are of very different environments.

Median Diameter: Skewness:

Figure 17 shows the relationship between median diameter and log of skewness. The distribution of points in this graph is not conclusive but it may indicate that the log of skewness varies from about zero in the coarser grains to both positive and negative values in the finer sediments, some of which, however, still possess a zero value. The points become diffused in the vicinity of median diameter .06, but it is to be noted that only a few sediments possess median diameters between .2 and .06. The skewness of the sediments, however, is very ambiguous

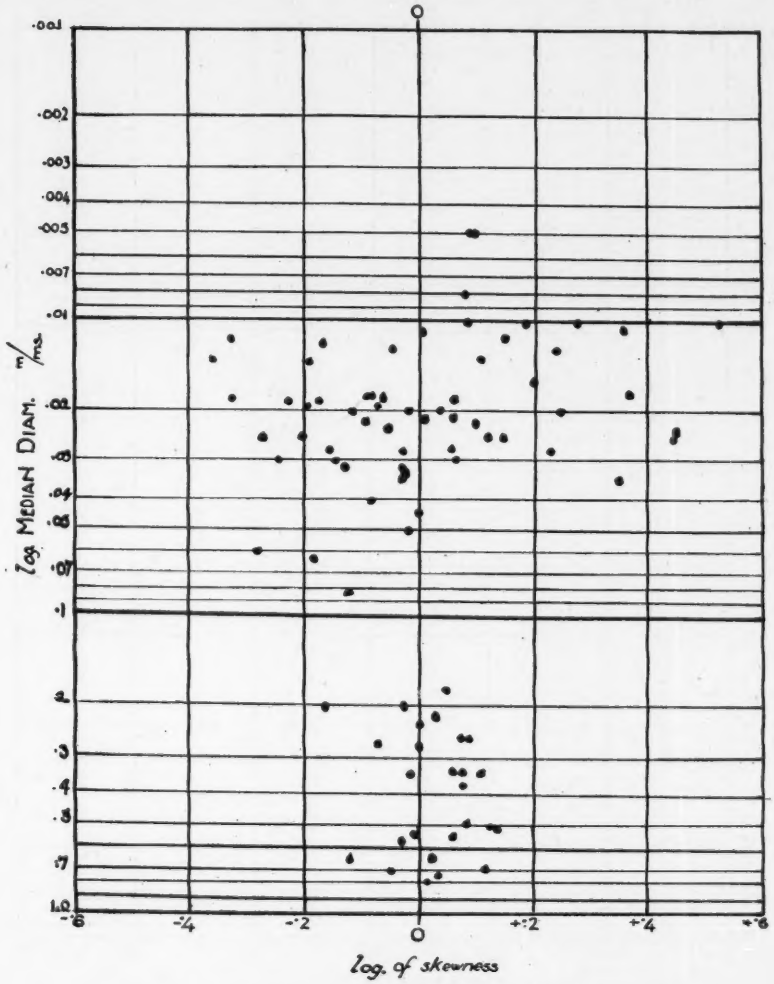

FIG. 17.—Relation between median diameter and log of skewness of Northern Red Sea sediments.

in its interrelation with other properties or with factors of environments as shown later.

Sorting: Skewness:

A graph was drawn to show the relation between sorting and skewness but the plotted points were diffused. They showed, however, that, on the whole, the well sorted samples possess low figures and that the less sorted sediments possess higher figures for log Sk in both negative

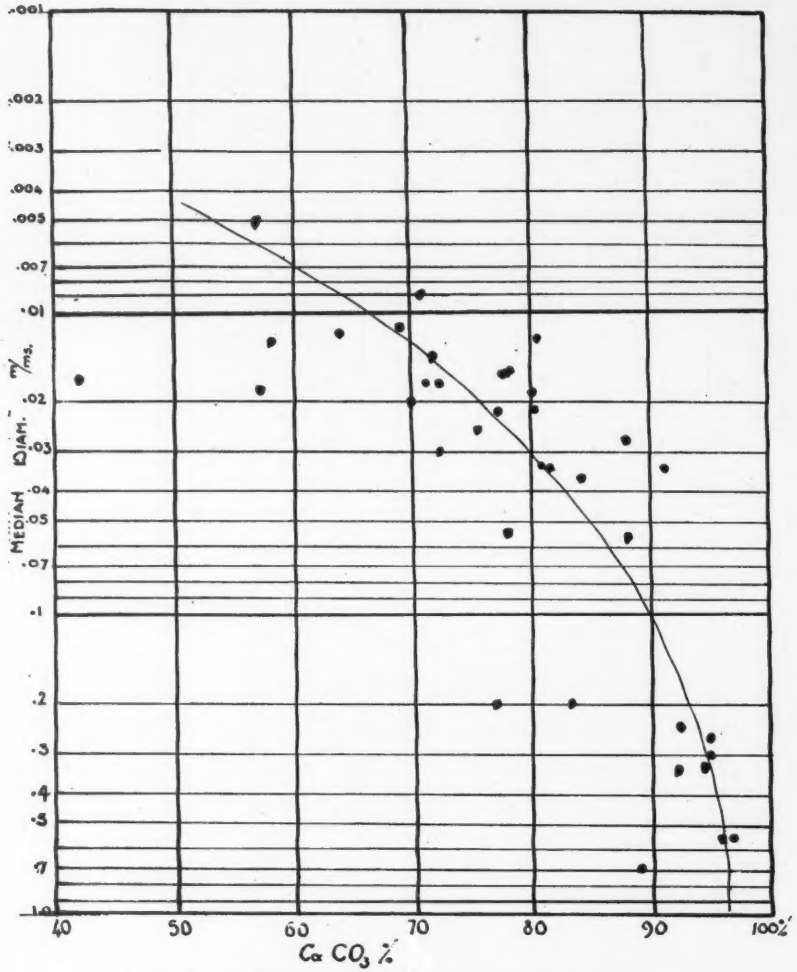

FIG. 18.—Relation between median diameter and $CaCO_3$% of Northern Red Sea sediments.

and positive directions as would be expected from the two previous relations.

Calcium Carbonate Content: Statistical Constants:

Figure 18 shows the relationship between median diameter and calcium carbonate content. The figure clearly shows that the percentage of $CaCO_3$ increases with increase of median diameter, and, as would be expected from the median: sorting relation, a graph drawn to show

the interrelation between $CaCO_3$ content and sorting factor showed that the well sorted samples possess the highest content of carbonate whereas the poorly sorted samples possess the lowest. The relation between log of skewness and carbonate content was also investigated by drawing a diagram, which showed that there is no conclusive relation.

Nitrogen and Organic Carbon Content: Statistical Constants:

Graphs were drawn to show the relation between the nitrogen percentages and organic carbon (evaluating the organic matter content of the sediments) on the one hand and the median diameters and sorting factors on the other. The graphs showed that both the nitrogen

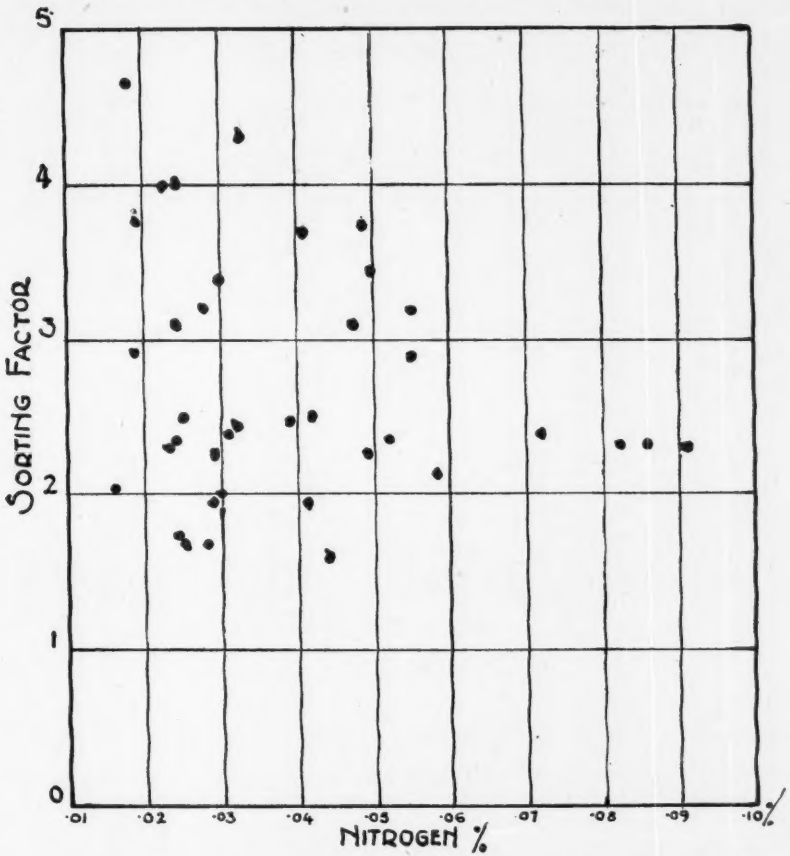

FIG. 19.—Relation between sorting factor and nitrogen percentage of *Northern Red Sea sediments.*

and organic carbon remain more or less constant irrespective of median diameter or sorting factor, except between median diameters .04–.02 mm. and sorting factors 2–2.5, (fig. 19) when they become conspicuously enriched. The log of skewness graph showed that it changes from a positive value to zero, thence to a negative value with increase of nitrogen content from .01 to .06 to .09 respectively.

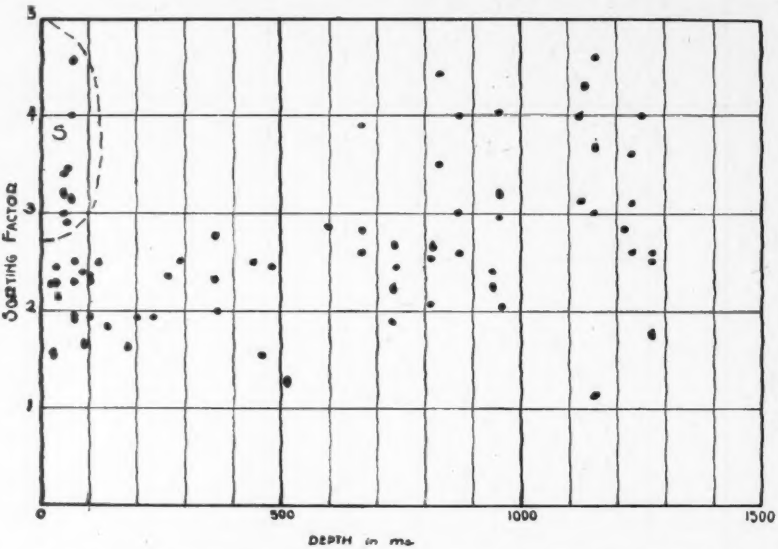

FIG. 20.—Relation between sorting factor and depth of Northern Red Sea sediments. The letter S marks the samples from the Gulf of Suez.

COORDINATION BETWEEN PROPERTIES OF SEDIMENTS AND CORRESPONDING FACTORS OF ENVIRONMENT

Knowing that the various properties of the sediments analyzed are more or less interdependent, with the exception of log of skewness, we can now proceed to coordinate these properties with the corresponding environmental conditions of deposition.

Depth: Statistical Constants:

When the median diameters were plotted against depth it was clearly shown from the curve drawn that on the whole increase in depth meant decrease in median diameter. The depth: sorting coefficient graph (see fig. 20) showed, as would be expected from the interrelation median diameter: sorting, that the well sorted samples are shallower than the less sorted samples. The shallower deposits are better sorted and coarser than the deeper.

It is interesting to note that in the graphs showing the interrelation between the various properties of the sediments, the points are interrelated in the same way irrespective of the environment from which the samples were secured. On the other hand, the points for the Gulf of Suez occupy a unique position in the depth curves. Thus in the depth: sorting factor diagram, for instance, the points for the Gulf of Suez sediments are all located in the field marked "S" in figure

20. The sediments of the Gulf of Suez, though of shallow origin, are finer and less sorted than those from the Gulf of Aqaba or the Red Sea shallow environments. On the other hand, the depth: log of skewness graph showed a confused relation and, in contradistinction with the sorting and median diameter graphs, the plotted points of the Gulf of Suez were not concentrated in a special area of the skewness graph. It seems that skewness is of little genetic value for the Red Sea sediments as judged from the sediments already examined.

Depth: Calcium Carbonate Percentage:

As could be deduced from the depth: median diameter and median diameter: carbonate graphs, the carbonate content was found to decrease with increase of depth.

Depth: Organic Matter Content:

Both nitrogen and organic carbon content of the sediments were plotted against the corresponding depths in two graphs, which showed that the organic content remained more or less constant at different depths, except at the relatively shallow depth of about 100 meters where an increase in organic matter content was apparent. It was previously shown that the sediments enriched in organic matter possess also median diameters between .04 and .02 mm. and sorting factors between 2 and 2.5. It is interesting to note that, though the rule is that the shallow and well sorted sediments are coarse, here the shallow (of depths about 100 meters) and well sorted sediments, which are also rich in organic matter, deviate from the rule, and are fine-grained sediments. It seems that the organic matter concentrates in the finer fractions relative to the carbonate particles, which concentrate in the coarser fractions. The organic matter was also found to accumulate more in basins than on slopes and ridges, as shown by samples collected at station 34 (over a submarine hill) west of Shadwan Island (9). It is interesting to note that the sample from the base of the hill, at the basin, is finer and less sorted than those collected from the slopes.

SUMMARY AND CONCLUSIONS

The paper deals with the mechanical analysis of some bottom samples amounting to fourteen cores and fifty grab samples collected during the Egyptian Preliminary Expedition to the northern part of the Red Sea in the R.R.S. "Mabahith" in 1934–1935. Both sieving and sedimentation methods (the pipette method) were used in the mechanical analysis. The fine sediments were thoroughly deflocculated by washing them free from electrolytes and subsequent stirring in dilute ammonia solution.

The Red Sea is unique amongst the seas of the world in the fact that no permanent streams flow into it and that only winds, mostly northwesterly, and rain torrents* contribute material to its bottom. The sea is probably unique also for its very irregular bottom topography (excluding the Gulf of Suez), hence, the nature and distribution of its bottom deposits are unmatched in other seas.

Though it is known that the physical constitution of marine sediments depends on many factors of environment and mode of origin such as the agents of transportation, flocculation effects, transporting influence of currents, depth, nearness to landmasses, amount of slope of bottom, effect of organisms etc., and that sediments deposited in several environments may have identical graphs (14), yet the mechanical analysis of the examined deposits gave many interesting results.

It is already apparent from the evidence that the statistical constants, the calcium carbonate and organic matter contents are interrelated in the same way,

* The authors had many experiences with torrents pouring into the sea, in its northern and southern parts, for several days with such a force as to make the sea water turbid for many kilometers off shore, giving it a similar color to that of the coastal plains.

irrespective of the environment from which the samples were secured. It was even noted that Hough gave a similar relation for median diameter: sorting factor for the sediments of Cape Cod Bay and Buzzards Bay, Massachusetts (5). It was found that, on the whole, the coarser sediments are better sorted and richer in calcium carbonate than the finer. The organic matter content increases between diameters .04–.02 mm. and sorting factors range between 2 and 2.5. It was shown also that the organic matter probably concentrates in the finer fractions relative to the carbonate particles, which concentrate in the coarser fractions. The interrelations of log of skewness and other properties are ambiguous.

As to interrelations of these properties with environmental conditions of deposition, it was found that the sediments are coarser and better sorted when they are secured from shallow or sloping bottoms or from near landmasses (including submarine ridges). The carbonate content has been found to decrease with increase of depth and the organic matter to concentrate in depths about 100 metres, being also greater in basins than on ridges and slopes. The skewness of the sediments, however, is ambiguous in its interrelation with other properties or with factors of environments. It seems that skewness is of little genetic value for the Red Sea sediments, as judged from the sediments already examined.

The topography of the bottom which affects the various factors of environment mentioned above seems to be the important factor in determining the physical constitution of the deposits. The Gulf of Suez, because of its flat bottom, has deposits with but little variation in their statistical data, in contradistinction with the deposits on the very irregular bottom of the Gulf of Aqaba or the Red Sea which have rapid changes in the corresponding statistical constants. The difference in environment is also shown by the fact that some of the statistical constants for the Gulf of Suez are located in special fields in the corresponding depth diagrams.[f] The sediments of the Gulf of Suez though of shallow origin are finer and less sorted than those of the Gulf of Aqaba or the Red Sea shallow environments. The data for the Gulf of Suez sediments are, in fact, comparable with those given by other normally sorted sediments from continental shelves; the Gulf of Suez is itself a shallow flat shelf filled with the surface water of the Red Sea and descending at its mouth abruptly to a depth five times greater than its own.

Though these results are of value in the reconstruction of paleogeographic conditions of deposition for ancient sediments, yet on account of the small number of samples examined, the results should be considered tentative and must inevitably remain subject to correction in the future. It is earnestly hoped, however, steadily to fill in the lacunae in our knowledge with fresh material to be collected when the main expedition for the exploration of the Red Sea is undertaken, and complete cartographic studies can be consequently accomplished.[g]

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[f] It is interesting to note that the same peculiarity was reflected on the mineralogy of the Gulf of Suez sediments, which are much richer in authigenic pyrite than either the Gulf of Aqaba or the Red Sea.

[g] The Egyptian Government postponed the expedition in 1935–1936, because of the Italo-Abbysinian War raging at that time; financial difficulties thereafter caused further delay; the present World War made it impossible for the "Mabahith" to resume its activities.

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FIG. 1, TABLES 1–2, AUGUST, 1944

THE MINERALOGY OF SOME BOTTOM DEPOSITS OF THE NORTHERN RED SEA

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ABSTRACT

The present paper deals with the mineralogy of sixty-four samples of bottom deposits from the Northern Red Sea collected during the "Mabahith" Expedition (1934–35). The special character of the wind-borne Red Sea deposits is discussed. The mineralogy of the sediments is uniform over the different provinces and thus contrasts with that of the usual basins of deposition. Local variations are, however, caused by contamination from local source-rocks or variation in the environmental conditions of deposition. The full value of the results can only be estimated when much more work has been done on the contributing rocks of the coastal areas.

INTRODUCTION

In the preceding article the authors gave the results of the mechanical analysis of the bottom deposits of the Northern Red Sea collected during the "Mabahith" expedition in 1934–1935 (9). A map showing the distribution of the samples is given in the same work. The present paper deals with the mineralogy of the deposits, a topic which received but little attention till the present. In fact the only work, as far as the authors are aware which deals with the mineralogy of the Red Sea sediments, is that of Sujkowski (21), who examined the sediments collected by S. S. "Endeavour" from the middle and south-eastern parts of the Sea in 1926–1928. Sujkowsky concentrated his study on the deep water deposits, especially their detrital material, which he considered to be derived from the continental dust by wind and accordingly gave a clue as to the features of sediments derived from desert regions. He recorded the following detritals:— amphiboles, pyroxenes, biotite, lime-soda and potash feldspars, feldspathoids, quartz, rare zircon and very rare tourmaline, but he failed to note garnet or rutile or any authigenic mineral, especially pyrite.[a] These minerals, however, and some other species were noted in the present investigation. Sujkowski concluded that the characteristics of such deposits, because of the absence of any chemical decomposition and lack of water transportation, are:

1—The freshness and angularity of detrital grains.

2—Their small size, which does not exceed 0.06–0.07 mm. (for mica 0.14 mm.).

3—The characteristic mineral composition, with the rareness or absence of common heavy minerals in sediments such as tourmaline, rutile, zircon, etc. and the preponderance of:

a. colored minerals

b. common rock-forming minerals (of igneous and metamorphic rocks)

c. easily weathered minerals.

The authors believe that these characters are not criteria for wind transportation as stated by Sujkowski,[b] though the deposits are actually carried mainly

[a] The minerals recorded are found in the fraction coarser than .005 mm. Sujkowski treated the sediments with hydrochloric acid before examination.

[b] The criticism of the work of Sujkowski, given in the following pages, does not, in any way, lessen the importance of his paper.

by wind giving them a more or less uniform mineral constitution in very widely separated parts of the Sea, without forming any sedimentary petrographic provinces (10). On the other hand local conditions (mostly depending on provenance) gave rise to variation in the frequencies or types of minerals present without affecting the general characters of the mineralogy of the deposits. Incidentally the evidence showed also that White's statement (23) that wind-borne sediments contain less frequent heavy minerals than water-borne sediments is invalid.

TECHNIQUE USED IN THE LABORATORY

The coarse samples, which are loose, whitish in color, and mainly formed of large organic carbonate particles, were separated by dry sieving into the following fractions: 2001–610, 610–271, 271–135, and 135–84 microns. The finer samples, which are usually gray, buff or rarely yellow in color, were thoroughly dispersed by washing them free from electrolytes, adding a dilute ammonia solution, and the subsequent stirring of the suspensions using a mechanical stirrer. The suspension was then screened through a 200 mesh (.084 mm.) sieve and the coarser material dried and again separated as for the coarser sediments. The finer material (less than the 200 mesh) will be the subject matter of a future publication.

All fractions of three representative samples were then separated by bromoform into heavy and light fractions. The constituents of their different fractions varied as follows:

>2.001 mm.—Shells and shell fragments, mostly of lamellibranchs and gastropods, carbonate particles and rare teeth, brachiopods and echinoid fragments. Quartz was not observed.

>.610 mm.—Do.—together with fragments of corals, bryozoa, foraminifera and annellids.

>.271 mm.—Do.—together with very few quartz grains.

>.136 mm.—Do.—together with mica flakes, iron ores and a few grains of the non-opaque heavy minerals.

>.085 mm.—Do.—the non-opaque heavy minerals are, however, more frequent.

The fraction >.085 mm. of all the samples was accordingly separated into heavy and light fractions. After determining the index figure (11, p. 236 and 239) the residues were mounted in Canada balsam and analyzed microscopically. Four hundred to seven hundred grains were counted from each crop and the relative frequencies of the minerals present were calculated. It is to be noted here that the minerals to be described are found in the fraction .136–.085 mm. and are accordingly coarser than the limits given by Sujkowski i.e. .05–.07 mm.[c], a small size, which he considered as characteristic for marine sediments transported by wind.

DESCRIPTION OF MINERALS

Table I gives the minerals recorded from each station, their percentages[d] and the corresponding index figures, whereas Table 2 shows the average percentages and range of minerals for the samples of each of the sections examined. Table 1 shows that the index figures (varying from 2.0 to .1) of the sediments are comparatively low for recent sediments but this is due to the presence of much non-detrital organic carbonate particles in them. An attempt was made to coordinate environmental conditions of deposition of the sediments and the corresponding index figures. A graph was accordingly drawn to show the relation between depth and index figure but no definite relation was detected, the points being diffused in the graph irrespective of

[c] Biotite flakes reach approximately twice this size, being exceedingly thin and thus more easily transported.

[d] The percentage of pyrite given is relative to all other minerals, carbonate grains were not counted and biotite was counted with the heavy minerals.

TABLE 1.

Section 1 (Gulf of Suez)

A Sample No.	B University No.	C Station No.	D Iron ores	E Biotite	F Amphiboles	G Pyroxenes	H Epidote	I Chlorite	J Tourmaline	K Sphene	L Apatite	M Zircon	N Rutile	O Garnet	P Staurolite	Q Kyanite	R Fluorite	S Andalusite	T Glauconite	U Spinel	V Olivine	W Anatase	X Pyrite	Y Index fig.
1	8503	1—Top	61	7	5	16	3	XX	XX	—	—	4	—	—	—	XX	—	—	—	—	—	—	41	not determined
		—Bottom	61	3	9	20	5			—	—	4	—	—	—		—	—	—	—	—	—	47	
2	8504	2—Top	24	15	18	28	4	XX	1	XX	XX	6	X	1	1	X	—	—	X	—	—	—	45	
		—Middle	25	14	16	26	5	XX	1	XX	XX	7	1	1	1	—	—	—	—	—	—	—	47	
		—Bottom	26	10	11	30	3	X	1	X	X	8	1	1	X	—	—	—	—	—	—	—	49	
3	8505	3—Top	40	13	14	19	2	X	3	—	1	3	XX	1	1	—	—	—	—	—	—	—	34	
		—Middle	42	11	16	21	2	XX	2	—	1	3	XX	1	1	—	—	—	—	—	—	—	38	
		—Bottom	47	9	18	20	2	X	1	—	1	3	XX	1	1	—	—	—	—	—	—	—	45	
	Average of section		43	10	13	22	3	X	1	X	X	5	X	1	1	X	—	—	X	—	—	—	43	

Section 2 (Gulf of Aqaba)

4	8506	57	14	35	38	2	3	4	X	—	2	1	—	—	—	—	—	X	—	—	—	—	1	.6
5	8507	48	26	23	31	4	1	2	1	6	5	1	1	—	—	—	—	—	—	—	—	XX	1	2.0
6	8508	49	23	6	34	9	3	—	4	6	7	3	5	—	—	—	—	—	—	—	—	XX	2	2.0
7	8509	52	22	14	32	11	3	3	1	4	5	3	3	—	XX	—	—	—	—	—	—	XX	—	.6
9	8511	54	39	10	27	5	7	3	2	2	1	2	1	—	—	—	—	—	—	—	—	—	—	.7
10	8512	55	32	7	35	8	3	5	X	1	7	3	X	XXXXX	—	—	—	X	—	—	—	XX	—	1.9
	Average of section		26	16	33	7	3	3	1	3	4	2	2		X	X	—	X	—	—	—	X	—	1.3

Section 3 (Ghardaqa-Shadwan-Senafir)

11	8513	43	33	15	28	6	5	3	1	3	3	1	1	1	XX	1	1	X	—	—	—	—	1	1.3
12	8514	41	33	9	27	5	7	1	2	2	3	9	1	1	—	—	—	—	—	—	—	—	XX	.3
13	8515	58	48	9	28	3	2	1	X	2	3	4	1	X	—	—	—	—	—	—	—	—	—	.2
14	8516	43	32	33	20	3	2	5	1	X	2	3	—	—	—	—	—	—	—	—	—	—	—	.4
15	8517	45	19	49	15	2	2	5	1	2	2	X	2	—	—	—	—	—	—	—	—	—	—	1.1
16	8518	40—Top	28	42	13	4	2	8	X	X	2	X	—	X	—	—	—	—	—	—	—	—	15	.1
		—Middle	21	45	17	4	3	6	—	—	1	2	—	—	—	—	—	—	—	—	—	—	30	.6
		—Bottom	19	58	12	4	—	6	—	1	—	—	—	1	—	—	—	—	—	—	—	—	29	.2

Section 3 (Ghardaqa-Shadwan-Senafir) (continued)

17	8519	7—Top	13	49	18	4	1	9	1	×	1	1	—	1	—	—	—	—	—	—	—	—	6	.2
		—Middle	13	43	22	6	1	9	1	1	1	2	×	1	×	—	—	—	—	—	—	—	3	.3
		—Bottom	14	43	22	7	1	8	1	1	1	2	×	1	×	—	—	—	—	—	—	—	3	.8
18	8520	26	33	4	24	15	6	2	4	2	2	5	2	1	—	×	—	—	—	—	—	—	9	.4
19	8521	32	32	5	31	15	7	2	2	1	2	2	1	1	—	—	—	—	—	—	—	—	5	.4
21	8523	21	40	6	20	11	9	3	1	—	5	2	1	1	—	—	—	—	—	—	—	—	11	.6
22	8524	20	24	3	33	24	7	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	6	.6
24	8526	15	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0
25	8527	27	28	2	34	11	9	2	1	2	3	5	2	1	—	1	—	—	—	—	—	—	6	.4
26	8528	14	25	8	28	20	8	2	1	2	2	1	×	1	—	—	—	—	—	—	—	—	9	.6
28	8530	18	25	22	28	8	9	3	1	1	1	1	—	×	—	—	—	—	—	—	—	—	10	.6
29	8531	19	46	3	28	8	6	×	1	1	3	2	1	1	—	—	—	—	—	—	—	—	12	.7
30	8532	34	27	10	29	9	10	1	2	2	2	2	1	×	×	—	—	—	—	—	—	—	7	.4
39	8541	37—Top	19	48	18	2	3	6	—	—	1	2	—	—	—	—	—	—	—	—	—	—	2	.7
		—Bottom	15	49	20	3	4	6	—	—	×	2	—	—	—	—	—	—	—	—	—	—	3	1.0
40	8542	22	32	9	31	6	7	2	1	1	2	3	×	×	×	—	—	—	—	—	—	—	7	.7
43	8545	23	33	5	30	8	5	3	2	3	3	2	2	—	—	—	—	—	—	—	—	—	8	.3
44	8546	33	33	9	32	8	5	2	1	1	3	3	×	×	—	—	—	—	—	—	—	—	7	.5
	Average of section		28	28	23	6	4	3	1	1	2	2	1	1	×	×	×	×	—	—	—	—	7	.5

Section 4 (Yuba-Mersa-Daba')

45	8547	67—Top	24	29	20	3	4	5	4	1	2	×	×	×	—	×	—	—	—	—	—	—	—	.3
		—Middle	27	32	24	4	5	6	3	×	2	×	×	×	—	×	—	—	—	—	—	—	×	.6
		—Bottom	27	29	22	5	6	4	2	1	2	×	×	×	—	—	—	—	—	—	—	—	×	.2
46	8548	66	18	38	20	3	7	6	3	2	1	×	×	×	—	—	—	—	—	—	—	—	×	.2
47	8549	62	20	4	49	10	6	1	1	2	3	1	1	1	—	—	—	—	—	—	—	—	×	.5
	Average of section		23	24	31	6	6	3	3	2	2	1	×	×	—	×	—	—	—	—	—	—	×	.5

Section 5 (Safaga-Mowila)

48	8550	75	46	10	24	5	6	1	1	2	1	1	1	×	×	—	—	—	—	—	—	—	×	.8
49	8551	69	47	5	24	4	6	2	2	2	2	2	2	—	—	—	—	—	—	—	—	—	2	.5
50	8552	74	49	4	23	5	5	—	4	4	2	2	—	2	—	—	—	—	—	—	—	—	2	.7
51	8553	76—Top	38	30	20	6	4	6	4	1	1	×	×	×	×	—	—	—	—	—	—	—	1	.2
		—Middle	34	28	18	4	4	5	2	1	1	×	×	×	—	—	—	—	—	—	—	—	×	.3
		—Bottom	27	29	16	5	4	4	3	1	1	1	×	×	×	—	—	—	×	—	—	—	1	.6

TABLE 1. (*continued*)

A Sample No.	B University No.	C Station No.	D Iron ores	E Biotite	F Amphiboles	G Pyroxenes	H Epidote	I Chlorite	J Tourmaline	K Sphene	L Apatite	M Zircon	N Rutile	O Garnet	P Staurolite	Q Kyanite	R Fluorite	S Andalusite	T Glauconite	U Spinel	V Olivine	W Anatase	X Pyrite	Y Sphene
Section 5 (Safaga-Mowila) (continued)																								
52	8554	77—Top	32	40	14	2	2	4	2	1	×	×	×	×	—	—	×	—	—	—	—	—	6	.2
		—Middle	33	37	12	2	2	3	2	1	×	×	×	×	—	—	×	—	—	—	—	—	7	.2
		—Bottom	34	34	13	2	2	2	2	1	×	×	×	×	—	—	×	—	—	—	—	—	8	1.3
53	8555	78—Top	34	37	14	2	4	3	2	—	1	×	×	—	×	—	—	—	—	—	—	—	3	.2
		—Middle	34	38	13	2	4	2	1	1	1	×	×	—	×	—	—	—	—	—	—	—	4	.3
		—Bottom	34	36	12	2	4	4	3	×	1	×	×	—	×	—	—	—	—	—	—	—	5	.1
	Average of section		42	21	20	4	5	2	2	2	1	1	1	×	×	—	×	—	×	—	—	—	3	.5
Section 6 (Qoseir-Brothers' No'man)																								
55	8557	88	46	2	13	22	7	1	1	×	1	2	×	×	—	×	—	—	—	—	2	—	3	.6
56	8558	87	40	4	11	26	9	2	1	×	1	2	—	—	—	—	—	—	—	—	1	×	3	.5
57	8559	83	52	8	18	6	6	4	1	×	1	2	—	—	—	—	—	—	—	—	—	—	3	.4
58	8560	82	51	13	12	7	7	1	3	1	1	1	×	×	—	—	—	—	—	×	—	—	3	.3
59	8561	81	40	6	24	17	5	2	2	1	1	1	×	—	—	—	×	—	—	—	—	—	2	.3
	Average of section		47	7	16	16	7	2	2	1	1	2	×	×	—	×	—	×	—	×	×	×	3	.4
Section 7 (Daedalus-Hanak)																								
60	8562	102	49	20	15	4	5	1	3	—	1	1	—	1	—	—	—	—	—	—	—	—	—	.2
62	8564	103	48	9	25	8	3	1	3	1	1	1	1	×	×	—	—	—	—	—	—	—	—	.3
63	8565	98	30	29	24	8	2	5	1	2	—	×	—	—	—	—	—	—	—	×	—	—	—	.1
64	8566	91	35	6	19	18	4	2	3	3	2	3	2	1	×	—	—	—	—	—	1	—	—	.4
	Average of section		40	16	21	9	4	2	2	2	1	1	1	1	×	—	—	—	—	×	×	—	—	.3
	Total average		36	17	22	10	5	2	2	2	2	2	1	1	×	×	×	×	×	×	×	×	8	.6

The cross means that the mineral is present but is less than 1%.

depth.[e] This may be attributed to the fact that wind, not water, is the main agent of transportation as there is no diminution of detrital minerals from shore-lines towards basins of deposition.

The authigenic mineral pyrite is to be dealt with first. It was previously mentioned that Sujkowski (p. 1) failed to detect pyrite in the sediments further south. It was, however, identified from the present sediments, and was present in great abundance at some stations, expecially in the Gulf of Suez, which has a special environment as shown in a previous work. Figure 1 gives the distribution of the minerals.

TABLE 2. *Average percentages and range of minerals of samples examined.*

Mineral	Section 1		Section 2		Section 3		Section 4		Section 5		Section 6		Section 7	
	Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range
Iron ores	43	24–61	26	14–39	28	13–48	23	18–27	42	27–49	47	40–52	40	30–49
Biotite	10	3–15	16	6–35	28	2–58	24	4–38	21	4–40	7	2–13	16	6–29
Amphiboles	13	5–18	33	27–38	23	12–34	31	20–49	20	12–24	16	11–24	21	15–25
Pyroxenes	22	16–30	7	2–11	6	2–24	6	3–10	4	2– 6	16	7–26	9	4–18
Epidote	3	2– 5	3	1– 7	4	1–10	6	4– 7	5	2– 6	7	5– 9	4	2– 5
Chlorite	×	×–×	3	— 5	3	×– 9	3	1– 6	2	— 6	2	1– 4	2	1– 5
Tourmaline	1	×– 3	1	×– 4	1	— 4	3	1– 4	2	1– 4	2	1– 3	2	1– 3
Sphene	×	— ×	2	— 6	1	— 3	2	×– 2	2	— 4	1	×– 1	2	— 3
Apatite	×	— 1	4	2– 7	2	— 5	2	1– 3	1	×– 2	1	1– 1	1	— 2
Zircon	5	4– 8	2	1– 3	2	— 9	1	×– 1	1	×– 2	2	1– 2	1	×– 3
Pyrites	43	34–49	×	— ×	7	— 30	×	— ×	3	×– 8	3	2– 3	—	— —

Pyrite—Pyrite is always authigenic and occurs in irregular patches and aggregates of minute crystals filling the hollow spaces of micro-organisms, especially the forams, showing their internal structure in a very striking manner. It is of interest to note that authigenic pyrite forms 34–49% (average of 43%) of the heavy residues of the Gulf of Suez sediments, whereas it is much less frequent or even completely absent in the sediments of both the Gulf of Aqaba and the Red Sea proper (see table 2). This suitable environment for the formation of authigenic pyrite in the Gulf of Suez may be attributed to 1) its richness in organic matter,[f] (16) which, being a reducing medium, will undoubtedly favor the formation of pyrite and not the oxides and, 2) its close proximity to the Egyptian oil fields and sulphur deposits, which are located in the neighborhood of the western coast of the Gulf of Suez at Ras Gharib and Ras Gemsa and on the eastern coast at Abu Durba. Few of the Red Sea samples, however, are rich in pyrite though not as rich as the Gulf of Suez. The richest sample (no. 16) possesses an average of 25% of pyrite and is located east of Shadwan Island in the Strait of Jubal and though the sample was secured from relatively deep waters (941 meters) its richness in organic matter[g] (16) helped in the formation of pyrites.

In the following pages the description and significance of the detrital minerals are given, starting with the light minerals.

A) MINERALS OF THE LIGHT FRACTION

The light fraction is composed mainly of micro-organisms in all the samples examined. These include various species of foraminifera (*Cristellaria, Nodosaria, Triloculina, Globigerina*, etc.) and shells of

[e] It is assumed that the amount of carbonate particles, which affects the index figure as well as authigenic pyrite, are constant.

[f] This is due to the fact that conditions in the Gulf are favorable to the growth of plankton and on account of the shallowness of the Gulf rapid sedimentation of organic debris takes place.

[g] This is due to the accumulation of organic residues transported from the Gulf of Suez by a strong outgoing current, which slows down west of Shadwan Island on the one hand, and down the continental slope into the great depths in the Strait of Jubal on the other hand.

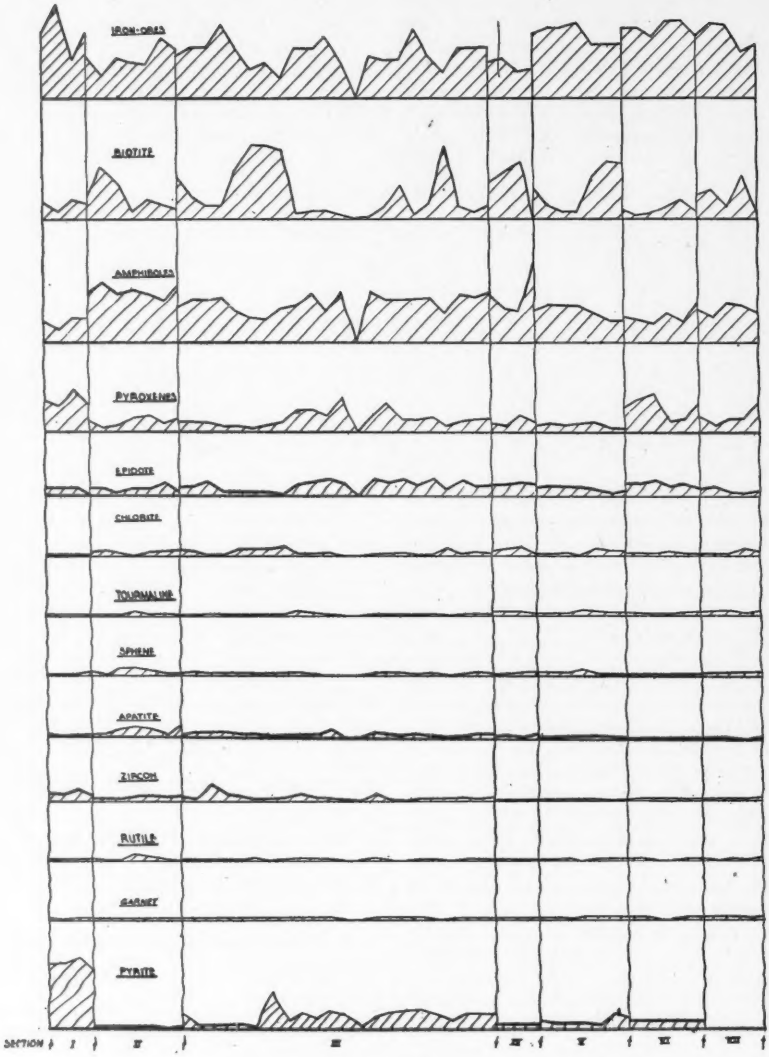

FIG. 1.—Distribution of the minerals in the different sections.

lamellibranchs.[h] Besides these organisms which are dominant, few shells of gastropods, ostracods, echinoid spines and plates, triaxial and monoaxial sponge spicules, bryozoan encrustments, radiolarians and diatoms are also present. A few clear carbonate grains are rhombohedral in shape and may be of authigenic origin.

The other detrital light minerals constitute only a very small percentage of the light fractions. The minerals recorded arranged in a decreasing order are quartz, muscovite and feldspar.

Quartz.—This mineral occurs in two different shapes: one is angular or subangular with inclusions mostly of apatite and zircon crystals, the other is remarkably well rounded. The rounded quartz grains are much more abundant than the angular quartz in the Gulf of Suez sediments but the contrary is the case in the Gulf of Aqaba or the Red Sea proper sediments. The difference in shape may indicate different sources, the rounded from pre-existing sediments, the angular from crystalline rocks. The dominance of pre-Cambrian crystalline rocks on either side of the Sea except to the west of the Gulf of Suez where only Carboniferous and post-Carboniferous sediments are present (together with minor Tertiary basaltic sheets) favors this assumption and may explain the relative abundance of the two varieties of quartz in the Gulf of Suez on the one hand and in both the Gulf of Aqaba and the Red Sea on the other. This is one example for the effect of local variation depending on the type of distributive rocks and some other examples are to be mentioned in the following text but these variations do not affect the mineralogy of the deposits of the Red Sea as a whole to the extent of masking their uniformity, as may be seen from tables 1 and 2 and from the following description. It is to be noted here that Sujkowski stated that the detrital particles exceeding .005 mm. in diameter are only rounded in the sediments obtained from shallow water and near the shore, but such rounded grains, representing different mineral species, were sparsely found in the deep water sediments of the northern Red Sea. It seems that the evidence of angularitymentioned by Sujkowski as one of the characteristic properties of the Red Sea sediments and thereby of desert dusts carried by wind is subject to discussion. The authors believe that further work on the sphericity and roundness of the minerals present is needed before any conclusion is drawn, as the mode of transportation does not seem to affect the angularity of fine mineral-grains (.07–.06 mm.), which Sujkowski worked out.

Some quartz grains show undulose extinction and few others are coated by thin films of yellow and reddish iron oxide. Such coated grains were undoubtedly transported as such (from the Nubian Sandstone or any others similarly stained sandy deposit from the mainland), as it is impossible that the ferric oxide could be formed in a reducing medium, which favored the formation of the sulphide as mentioned above.

Muscovite.—Muscovite, in irregular or rarely oval basal flakes, occurs in less abundance than quartz. The flakes are usually devoid of inclusions and few grains show undulose extinction.

Feldspars.—These are represented by a few grains in each slide. Orthoclase, microcline and plagioclase are recorded and are always fresh and angular. Their freshness is an indication of mechanical weathering but not necessarily of wind transportation as remarkably fresh feldspars and easily weathered ferromagnesian minerals (including the least stable mineral olivine) are present in the water-carried Nile deposits as shown by a recent work carried by the senior author (see also 13). This question of the freshness of the detrital minerals of the Red Sea sediments will be further discussed.

[h] Some shells give a negative uniaxial figure between crossed nicols due to the concavity of the shells acting itself as a convergent lens.

B) MINERALS OF THE HEAVY FRACTION

The minerals will be described and discussed in the order given in table 1, in which the minerals are arranged, as far as possible, according to their relative abundance.

Carbonates.—Carbonate grains are always abundant in the heavy crops and are not counted. Aragonite is the most common carbonate and is of organic origin, but calcite, not well separated into the light fraction, is also present. Members of the dolomite-ankerite group may possibly be present but no attempt was made to identify them. Some of the aragonite grains are either uniformly stained in pink, mauve or purple colors or only part of the fragments are colored. Some of the stained grains show cleavage and pronounced pleochroism (X = mauve, Z = colorless) and are at first sight mistaken for glaucophane or dumortierite except that they show twinkling.

It is interesting to note that pleochroic aragonite is not recorded in Milner's Sedimentary Petrography. Dispersion of the light along a certain direction in the crystals may be the cause of the apparent pleochroism, but it is difficult to explain the partly "stained" particles by this assumption. It is highly possible that a staining matter arranged its atoms or molecules in definite directions in the crystals and thus formed a part of its crystal lattice.

Iron Minerals.—Under this heading, ilmenite, magnetite, hematite and limonite are grouped together. They are not counted separately because it is not easy to distinguish between ilmenite and magnetite, and again limonite or hematite may be present as thin films enveloping magnetite grains. The grains are rounded and always form an important part of the heavy fractions, ranging from 13 to 61 per cent. It is interesting to note that the percentage of both authigenic pyrite and detrital iron minerals added together is highest in the Gulf of Suez. This is in harmony with the fact that the Gulf of Suez sediments are also the highest in the percentage of iron as proved chemically (16).

Biotite.—The frequency of biotite ranges between 2 and 58 per cent in the different samples as shown in table 2. It is found in two distinct fresh varieties: a) a dark-brown, b) a dirty-green variety, comparable to that usually found in contaminated rocks. Rutile and zircon are the usual inclusions. Few grains are either completely or partially altered to chlorite. The flakes are mostly irregular but perfectly oval grains of both varieties are present in the Gulf of Suez. Such perfectly oval grains were observed by the senior author from the Nile sediments and, as mentioned later, the authors state that the Nile sediments of the Delta may have contributed easily weathered ferromagnesian minerals, including the oval shaped biotite, to the Gulf of Suez in a similar fresh state. If this is true it shows that biotite and other ferromagnesian minerals can survive two cycles of sedimentation and even survive them without affecting their freshness. In fact, there is no reason why the remarkaby fresh ferromagnesian minerals of the Nile, which stood one cycle of sedimentation, could not be carried once more by wind and deposited in the Gulf of Suez in a similar state of freshness.

Variation in the relative frequencies of biotite in the different sections and in samples of the same section seems to depend on changes in wind velocity during transportation and on the degree of quietness of their marine environment. On the other hand local variation in the distributive rocks undoubtedly played a part in this respect (3, chapter VII). The samples west of Shadwan Island, for instance, which is formed of mica schists and acid and intermediate rocks as observed by the senior author during the present Expedition caused enrichment of biotite in these neighboring sediments (nos. 16 and 17), whereas the sediments collected from the Brothers' slopes, which are formed of basic rocks nearly devoid of mica (18) are relatively poor in biotite.

Amphiboles.—Uhder this heading four "species" are recorded and described namely: dirty-green hornblende, bluish-green hornblende, brown hornblende and actinolite. The frequency of amphiboles varies from 5 to 48 per cent in the different sediments; the dirty-green variety always exceeds the others; whereas the brown variety and actinolite are very rare and the latter is usually the least abundant.[i] All the grains are remarkably fresh and are very rarely decomposed into chloritic material. It was noted that in the Gulf of Suez, for instance, the completely altered crystals of amphibole, as well as pyroxene, became more abundant as the downward trend of the core increased (percentage of decomposed amphibole varies from .2 to 1.8 as shown in Table 3. This might be due

TABLE 3. *Showing percentage of decomposed amphiboles and pyroxenes.*

No. of samples		% of decomposed amphiboles	% of decomposed pyroxenes
1	Top	.2	.4
	Bottom	.9	1.4
2	Top	.6	1.4
	Middle	.8	2.0
	Bottom	1.2	3.0
3	Top	.4	.6
	Middle	1.0	1.4
	Bottom	1.8	2.1

to post-depositional processes (4, 8, 17 and 21), which will yield simplification of the mineral detritus during geological time. If this is correct, because there is the possibility that these decomposed grains were transported as such and that their increase downward is accidental, the hydrogen sulphide generated during diagenetical processes undoubtedly helped in the alteration of the mineral particles, because the slightly alkaline seawater is a stabilizing medium rather than a destructive one (18).

[i] The same relative abundance is recorded from the Nile sediments at Cairo.

The hornblende crystals are compact and angular and show some tendency for prismatic habit. The grains show marked pleochroism from yellowish-green to dirty-green, from green to bluish-green (with $-2V = 82°$ and $Z\ c = 30°$)[j], and from pale-brown to dark-brown in the three varieties of hornblende. Black iron minerals are present as inclusions. Actinolite is fibrous, very pale green in color and unpleochroic. The amphiboles summed together are always more abundant than the pyroxenes, except in the sediments from the slopes of the Brothers' Islets in the south (nos. 55 and 56) and from the Gulf of Suez. These are two other examples of the effect of local variations on the mineralogy of the sediments. The abundance of the pyroxenes on the slopes of the Brothers' is due to the fact that they are formed of basic rocks (18). It was difficult at first to account, however, for the relative abundance of pyroxenes in the Gulf of Suez, especially as the Gulf is bounded in its immediate vicinity by sediments on its eastern side and mainly by both sediments and acid and intermediate types on its western side, but this may be explained by the suggestion that the important northwesterly winds passing over the Delta of the Nile carried its fine detritals during the frequent sand storms and subsequently deposited them in the Gulf of Suez. The Nile sediments contain more abundant pyroxenes than amphiboles as shown in a recent work by the senior author.

Pyroxenes.—Both monoclinic and rhombic pyroxenes are recorded. Their total relative frequencies vary from 2 to 30 per cent. The monoclinic pyroxenes comprise five varieties: grayish-brown augite, yellowish augite,[k] colorless augite, diopside and diallage. They are all unpleochroic and the grayish-brown variety

[j] Data determined by the use of a Fedorov stage. They compare fairly well with those of a bluish-green hornblende from the Nile sediments, as determined by the senior author.

[k] With $+2V = 56°$, the cleavage is not clear.

is always dominating. The colorless augite and diopside are very rare and are completely absent in some sections. The diallage is also very rare and is schillerized and the inclusions are mostly reddish iron oxides. The grains are angular to sub-angular and are very fresh with but few grains partially altered into a yellowish serpentinous material. The colorless and diopsidic varieties were not seen in a decomposed state.

The rhombic pyroxenes are very rare and are represented by both hypersthene and enstatite. The hypersthene shows marked pleochroism from green to pink and is rarely altered along cleavage planes into a brownish serpentine. Black iron ores are common inclusions. The colorless rhombic pyroxenes were identified as enstatite.

Epidotes.—Pistachite, zoisite, clinozoisite, thulite and a much turbid rounded variety were recorded. The total frequency of the epidotes varies from 1 to 10 per cent. Pistachite, which occurs in angular or sub-angular broken crystals is the most abundant except in the sediments of the Gulf of Suez and few samples from near Tiran Island where the turbid and rounded grains are more abundant than pistachite. It is believed that the turbid and rounded variety is derived from pre-existing sediments. The abundance of sediments on the western side of the Gulf may thus explain the dominance of the rounded turbid variety over the fresh pistachite. Zoisite and clinozoisite, occurring also in angular crystals are very rare. Thulite, showing pleochroism from rose to colorless, was recorded only from the sediments located on the slopes of the Brothers' Islets. It is interesting to note that thulite was identified from the basic rocks of the Brothers' (sample no. 3472 housed in the Geological Department of Fouad I University).

Chlorite.—Chlorite varies from less than 1 to 9 per cent. Besides its occurrence as alteration product after biotite, other grains seem to be primary. These are pale-green, non-pleochroic and occur in rounded or oval grains and may be derived from pre-existing sediments, but irregular flakes are present, some of which show undulose extinction and suggest derivation from crystalline rocks. The rounded grains are dominant in the Gulf of Suez.

Tourmaline.—The percentage of this mineral varies from less than 1 to 4 per cent. It occurs in four varieties differing in color, namely brown, bluish, violet and green varieties, exhibiting marked pleochroism. The brown variety is the commonest. Most of the particles are prismatic with rounded or angular edges but well rounded grains are occasionally observed. The presence of these two varieties, namely the prismatic and rounded, suggest derivation from crystalline and sedimentary formations respectively. Inclusions, including zircon crystals, rutile needles and opaque particles are more abundant in the brown variety than in the others. A rare light indigo-blue variety (indicolite) in very clear grains is also present. It is interesting to note that exactly similar grains were observed in the Nubian Sandstone of the Eastern Desert of Egypt (19).

Sphene.—Sphene varies from less than 1 to 6 per cent. It is faint brownish in color. The grains possess pitted surfaces and are sub-angular or angular but rare, nearly complete spindle-shaped crystals are present. Some grains contain iron minerals as inclusions. Sphene is more abundant in the Gulf of Aqaba than in the Gulf of Suez or Red Sea sediments.

Apatite.—Two varieties of apatite were recorded, namely, 1) a clear angular to sub-angular prismatic variety, which is devoid of inclusions and 2) rounded or oval grains, which are crowded with inclusions composed mainly of opaque material. The relative frequencies of the two varieties vary in the different samples.

Zircon.—The frequency of zircon varies from less than 1 to 9 per cent. Colorless, purple and yellow varieties are distinguished. It ranges from water-clear crystals devoid of any inclusions except for some fluid cavities to grains possessing

numerous inclusions (comprising apatite crystals and smaller zircon grains). Worn, rounded and oval grains (usually of the purple and yellow varieties) as well as idiomorphic crystals (usually the colorless) are present. The presence of these two varieties suggests that they are derived from two different sources, the rounded from sediments and the idiomorphic from crystalline rocks. The rounded grains are more abundant than the idiomorphic crystals in the Gulf of Suez, whereas the reverse is the case in the Gulf of Aqaba or the Red Sea sediments. This may be due to local variation related to the dominance of sediments on the sides of the Gulf of Suez.

Rutile.—This mineral is recorded from most of the sediments and its frequency reaches up to 5 per cent. It occurs in ovoid, deep reddish-brown or yellowish grains, showing marked pleochroism. Less frequently angular to sub-angular prismatic crystals, often striated parallel to the vertical axis are present. Some of the angular crystals show polysynthetic or heart-shaped twinning.

Garnet.—The freqency of garnet varies from less than 1 to 2 per cent. Three varieties were recognized, colorless, pink, and yellowish-brown. The colorless usually dominates. The grains are rounded and inclusions are rare. A few etched grains, having a scaly patterned surface and similar to those figured by Wilgus (23, p. 86) were seen. Exactly similar grains were recorded from the Nubian Sandstone of the mainland to the west (19). Broken dodecahedrons are also present. At least two sources of the garnet are suggested: the Nubian Sandstone on the one hand and crystalline rocks on the other.

Staurolite.—Staurolite when present always forms less than 1 per cent except in some samples of the Gulf of Suez where it forms up to 1 per cent of the heavy minerals. It is angular and exhibits strong pleochroism (X = nearly colorless, Y = pale yellow and Z = golden yellow). Inclusions, commonly carbonaceous matter, are rarely present and a few grains show a pitted scaly patterned surface[1] which is more pronounced than that shown by the pitted garnets mentioned above. Staurolite seems to have been derived from the Nubian Sandstone where it forms about 20 per cent of the heavy non-opaque minerals of the sandstones (19). Staurolite is, however, recorded from a few localities in the Eastern Desert but is very rare in the Pre-Cambrian of Egypt (1).

Kyanite.—Kyanite is, on the whole, slightly less frequent than staurolite. It occurs in colorless stout prismatic grains with rounded edges and shows the two rectangular cleavages. Inclusions are absent. Kyanite like staurolite is recorded from a few localities in the Eastern Desert of Egypt.

Fluorite.—This mineral was recorded from only three samples (from the entrance to the Gulf of Aqaba, Safaga-Mowila and Qoseir-Brothers' sections) It is always less than 1 per cent and occurs in very rare sub-angular colorless grains. Fluorite is recorded from the Pre-Cambrian of Sinai and the Eastern Desert.

Andalusite.—Andalusite is recorded from three samples located in the Gulf of Aqaba and at its entrance. It is very rare and occurs in clear prismatic grains with their edges rounded. Pleochroism from pink to colorless is displayed by all the grains. It is interesting to note that Hume recorded contact-altered pelitic rocks bearing andalusite, showing the characteristic pink pleochroism, from the southeastern part of Sinai (12, p. 607), otherwise andalusite is not recorded from Egypt. This is another example showing the effect of source-rocks on the mineralogy of the neighboring sediments.

Glauconite.—Glauconite is represented in two samples only by two grains, one from the Gulf of Suez section and the other from Safaga-Mowila section. The two grains are unpleochroic green in color and rounded, showing aggregate polariza-

[1] Similar staurolite grains are recorded from the Nubian Sandstone (6 and 20).

tion colors. The grains are most probably detrital in origin. Glauconite was not seen either filling the hollow spaces of organisms or forming after biotite.

Spinel.—This mineral is recorded from two samples in the two southernmost sections. It is represented in the two samples by a bluish-green isotropic angular variety, represented by a very few grains.

Olivine.—Olivine was also recorded from the same two sections, from the slopes of the Brothers' Islets and from station no. 64, north-west of Sheibara Island, but in greater abundance than spinel as it forms 1 or 2 per cent of the heavy minerals. The mineral is present in angular colorless fresh grains on the Brothers' slopes and exhibits a yellowish tinge in the other occurrence. The optic axial angle of the colorless olivine from the Brothers' slopes equals 85° and it is interesting to note that remarkably fresh olivine crystals (with $-2V = 84° - 78°$) were described from the shore-debris and from a compact conglomerate on the Brothers' Islets (18). The presence of olivine in the bottom sediments as well is another example of the effect of local variations on the mineralogy of the Red Sea deposits.

Anatase.—This mineral occurs in three samples, two from the Gulf of Aqaba and one from the slopes of the Brothers' Islets and is represented by a very few grains. It occurs in angular dark bluish-gray, nearly opaque grains.

Rock-fragments.—Besides the separate mineral grains recorded in the previous pages a few rock-fragments are occasionally present in the heavy crops. A hornblende schist is recorded from the Gulf of Aqaba, whereas a fragment of a dolerite is recorded from the slopes of the Brothers' sediments. Dolerite is recorded from the Islets by the senior author (18).

SUMMARY AND CONCLUSIONS

The present paper deals with the mineralogy of the bottom deposits collected during the "Mabahith" Expediton to the northern part of the Red Sea in 1934–1935. The sediments were fractionated and the fraction lying between .135 and .085 mm. was separated by bromoform into light and heavy fractions and was examined microscopically. Carbonate particles of organic source form the greater part of the sediments and the following minerals are recorded: pyrite, calcite, quartz, moscovite, orthoclase, microcline, members of the plagioclase series, pleochroic aragonite,[m] ilmenite, magnetite, hematite, limonite, biotite, hornblende (three varieties), actinolite, augite (three varieties), diopside, diallage, hypersthene, enstatite, pistachite, zoisite, clinozoisite, thulite, chlorite, tourmaline, sphene, apatite, zircon, rutile, garnet, staurolite, kyanite, fluorite, andalusite, glauconite, spinel, olivine and anatase, amounting to about 38 species.

The characteristics of the minerals present in the middle and south eastern parts of the Red Sea are beautifully summarized by Sujkowski and his description agrees in its essential parts with the minerals found farther to the north. The relative frequencies of the minerals recorded show that the common heavy minerals of sediments (especially of the older formations), such as tourmaline, rutile, zircon, etc. are rare or even absent in some parts of the Sea, whereas the easily weathered, colored minerals, and the common rock-forming minerals of crystalline rocks are present in abundance in a fresh state.

Sujkowski stated that such an assemblage of minerals characterizes sediments derived from desert regions by wind. This statement is, however, subject to discussion and the authors believe that these characters are neither criteria for wind transportation nor of desert regions. The minerals of the bottom sediments of the Red Sea exhibit these characters mainly, or at least in part, because they were derived in their greater part from crystalline rocks, which bound the Sea on both sides. In fact, the recent dunes of the great

[m] Pleochroic aragonite (X = mauve, Z = colorless) is not recorded in Milner's sedimentary petrography.

African Sahara, where conditions that favor mechanical disintegration rather than chemical decomposition of source-rock prevail, but where sediments and not crystalline rocks dominate (14) contain a totally different assemblage (rich in iron minerals, tourmaline, zircon, rutile, etc.) from that of the Red Sea sediments (2 and 23). On the other hand, the Nile sediments, worked out by the senior author and which are water-borne, gave an assemblage of minerals with the same characteristics as those of the Red Sea bottom deposits. Both formations, though of two different modes of origin, are remarkable examples for the richness of recent sediments (derived from crystalline rocks) in vulnerable minerals. The sediments near Cairo, though carried for hundreds of kilometres, contain over thirty mineral species in a very fresh state, many of which stand at the top of a list of minerals arranged in an increasing order of stability.

The angularity of the grains and their small size, stated by Sujkowski to be characteristic for the mode of origin of the Red Sea sediments, seems to be invalid and further evidence is wanted on the subject before any conclusion is drawn. It was noted that the minerals recorded in the present work are coarser than the limits given by Sujkowski, who considered their fineness as characteristic for wind transportation.

The mineral assemblage of a sediment depends on three main factors:

1. Nature of distributive rocks.
2. Type of weathering and mode of transportation.
3. Post-depositional processes, leading to simplification of detrital grains and increase in authigenic minerals.

Sujkowski took into account the second factor mentioned but not the first, which is of great importance in the case of the Red Sea sediments. The third is not working in recent sediments or is of negligible importance. The characteristics of sediments derived from deserts by wind are, accordingly, not those given by Sujkowski. At the same time the statement of White (23) that wind-borne sands contain less frequent heavy minerals than water-borne sands and that the heavy minerals are less frequent in larger deserts than in smaller desert areas is invalid as he did not take into account the factor of distributive rocks in this case also.

The detrital minerals of the Red Sea sediments were transported to the sea mainly by wind, mostly from the rocks in its immediate vicinity,[n] though rain-torrents and waves undoubtedly contributed smaller amounts of material. The mineral constituents of the sediments are uniform[o] in all parts of the Sea and they all show the same general characters, whether collected from the southern, middle or northern portions of the Sea.[p] The usual heterogeneity of the mineralogy of marine sediments, producing well defined "sedimentary" petrographic provinces (10) and which are in many cases due to transportation by rivers, is not known in the Red Sea bottom deposits. Again, no diminution of detrital minerals from shore-lines towards basins of deposition was detected and this may also be due to wind transportation. On the other hand, local conditions gave rise to variation in the frequencies or types of minerals present without affecting the general characters of the mineralogy of the deposits. Variation in authigenic minerals is due to variation of the environmental conditions of deposition, on the other hand, variation in detrital minerals is mainly attributed to differences in the source-rocks, but varia-

[n] It is interesting to note that Wade (22) showed that the sands round Gebel Zeit, in the northern Eastern Desert of Egypt are mostly derived from rocks in its vicinity, the sand itself playing a part in the disintegration of the source-rocks.

[o] Sujkowski (21) states that it is not possible to differentiate between one sediment of deep water bottom and another by a study of their minerals.

[p] It is interesting to note that the shallow and near-shore sediments gave the same general characters as those of the deeper samples.

tion of wind velocity and direction, as well as of environments of deposition (such as strength and direction of currents, etc.), played a part.

Authigenic pyrite is present in great abundance (average of 43 per cent of the heavy minerals) in the Gulf of Suez, which has a special environment as shown in the preceding article and is much less frequent or even completely absent in the sediments of both the Gulf of Aqaba and the Red Sea proper. The suitable environment for the formation of authigenic pyrite in the Gulf of Suez is attributed to its shallowness, richness in organic matter and its close proximity to the Egyptian oil-fields and sulphur deposits, located on its sides. It was noted that the percentage of both authigenic pyrite and detrital iron minerals added together is highest in the Gulf of Suez; this is in harmony with the fact that the Gulf of Suez sediments are also the highest in the percentage of iron as proved chemically (16).

Examples of the effect of local variations on the detrital grains were discussed. The presence of 1) feldspathoids in the sediments described by Sujkowski from the middle and south-eastern parts of the Sea and their presence in the Yamano-Abbyssinian Tertiary alkaline volcanic provinces as well, and their absence in the bottom sediments and extreme rarity in the source rocks from the north, 2) the presence of olivine, thulite,[q] and dolerite in both the Brothers' Islets and the bottom sediments collected from their submarine ridge, 3) the presence of andalusite in the Gulf of Aqaba sediments and in those from its entrance on the one hand and its record in a similar variety from the south-eastern part of the Sinai Peninsula on the other and 4) the dominance of rounded quartz, zircon and turbid epidote grains over angular or idiomorphic crystals of the same species in the Gulf of Suez (contrary to the Gulf of Aqaba and Red Sea sediments) and the abundance of sedimentary formations on its sides, are some examples of the effect of local variations.

The junior author wishes to convey his thanks to Prof. O. Zdansky for laboratory facilities provided at the Geology Dept., Fouad I University.

[q] This mineral and others, though of extreme rarity, are of great provenance significance (7).

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FIGS. 1–2, TABLE 1, AUGUST, 1944

HEAVY MINERALS OF COLORADO RIVER TERRACES OF TEXAS

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ABSTRACT

This investigation was made to determine if heavy minerals could be used to distinguish between the terraces of Colorado River of Texas. The ratio of hornblende to black opaque minerals is very small in the oldest terrace deposits, but this ratio increases rapidly in the deposits of each of the younger terraces.

The distinctive mineral ratios found in the various terraces in the vicinity of Austin persist at least as far as Altair in Colorado County, which is located in the flat coastal plain. The terraces remain in the same order throughout this distance and the older terraces are not overlapped by younger ones as has been suggested.

INTRODUCTION

The purpose of this investigation was to find criteria, using heavy minerals, by which the Colorado River terraces could be identified and correlated throughout the course of the river. So far as the writer has been able to find in the literature, heavy minerals previously have not been used to distinguish and correlate terraces along rivers. The work on the Colorado River terraces shows that significant differences in the ratio of the heavy minerals can be detected. These results may be applied to other drainage areas having a similar history.

The terraces examined are located between Mansfield Dam in Travis County and Altair in Colorado County, paralleling the present course of Colorado River. The area between Mansfield Dam and Montopolis Bridge near Austin was mapped and investigated in detail to determine the typical heavy mineral assemblages of the various terraces. Additional samples were taken from the various terraces farther downstream for identification and correlation.

Deussen traced these terraces downstream and located the Asylum terrace as far downstream as the flat 5.9 miles north of La Grange and the lower terraces as far as Altair. Later, Weeks, tracing the terraces downstream, reported the Asylum terrace overlapped by the younger terraces. The writer's observations are essentially in agreement with Deussen's conclusions and not with Weeks'.

DESCRIPTION OF THE COLORADO DRAINAGE BASIN

The Colorado River originates in the plains of west Texas in an area of Triassic rocks and flows across Permian, Pennsylvanian, Ordovician, Cambrian, pre-Cambrian, and Cretaceous rocks before it reaches the area examined. In the area examined it flows across Cretaceous and Tertiary rocks.

Heavy minerals have been examined in only a few of the rocks of the Colorado Drainage Basin. Sidwell reports the following heavy mineral assemblage in the Triassic Santa Rosa sandstone of New Mexico, the equivalent of which probably extends into Texas: magnetite, ilmenite, garnet, tourmaline, hematite, olivine, rutile, zircon and biotite. Paige mentions only a few of the heavy minerals of the pre-Cambrian, namely: hornblende in some of the igneous rocks and in the Packsaddle schist; biotite in granites and mica schist; magnetite in gneiss, schist and granite; tourmaline in schist; epidote in diorite; zircon in hornblende granite; titanite in schist and granite; augite in schist; apatite in schist, granite,

gneiss and diorite; and fluorite in opaline granite. Garnet, monazite and rutile are common in schist, gneiss and granite. The heavy minerals furnished by the various sandstone members in the Paleozoic and Cretaceous are unknown.

The Tertiary rocks of the Colorado drainage are dominantly clastic with an abundant heavy mineral content. A short distance below the Cretaceous-Tertiary contact the effect of their mineral content is noticed. In the Yegua formation Lonsdale found traces of leucoxene, ilmenite, tourmaline, zircon, kyanite, staurolite, rutile and limonite. In the Fayette formation Wendler found magnetite and zircon abundant; limonite, pyrite, ilmenite, leucoxene and biotite common; kyanite, tourmaline, rutile, monazite, spinel, garnet and anatase rare. Bailey found traces of magnetite, barite, green hornblende and titanite in the Frio formation and magnetite, biotite, muscovite, zircon and barite in the Oakville formation. He also made studies of the Lagarto and Goliad formations, but the results are purely qualitative and practically the same as those listed above.

The Balcones fault line scarp crosses the area examined. Upstream from it the Colorado is entrenched in a steep walled valley cut in the Lower Cretaceous Glen Rose alternating beds of hard limestones and soft marls. The valley of Colorado River in this area is narrow, and its flood plain is rarely three times the width of the stream. The older terraces upstream from the fault are limited to small remnants perched on the inside bends of the entrenched meanders. Downstream from the fault, the river flows through a broad valley cut into the less consolidated sediments of the Upper Cretaceous and Tertiary age. This reach of the stream is bordered by an extensive flood plain and the higher terraces are usually well preserved.

DESCRIPTION OF COLORADO RIVER DEPOSITS

The terrace deposits from which heavy minerals were obtained are thick and well assorted, and cross-laminated sands and gravels rest on distinct benches cut in the underlying rocks. In Austin and its vicinity, the terraces are all well preserved on both sides of the river. Earlier work on Colorado River Terraces was mostly done in and near Austin and, consequently, they bear names of cultural markers in Austin. Older gravel deposits including the Uvalde formation and the Delaney gravel (used here for the first time) are devoid of sand; consequently heavy minerals are absent.

Uvalde Formation.—The Uvalde formation near Austin consists almost wholly of rounded flint cobbles and boulders and occasional limestone pebbles. Accumulations of this material are extensive coastward from the Balcones fault. In the vicinity of Austin, the accumulations are on hilltops at elevations up to 320 feet above river level. They are not at a definite level and do not form a continuous deposit. It is not known whether these flint gravels were deposited in place as an extensive terrace or in a series of fans, but it is apparent that erosion has produced some settling to lower levels. Feldspar is not found in the Uvalde formation but is present in all later terraces.

Delaney Gravel.—A scattered gravel deposit, consisting of flint, chert, quartz and some feldspar pebbles, tops a hill 245 feet above river level on the Delaney ranch along the Bee Caves road 3 miles west of Austin. This is lower than the Uvalde formation. The feldspar is derived from the pre-Cambrian of the Central Mineral region. Similar material 258 feet above river level is located 1 mile south along the ridge between Barton Creek and the Fredericksburg road. Another deposit is located on a gentle slope 260 feet above the river west of the main Balcones fault and three-quarters of a mile southeast of the mouth of Bull Creek. The pebbles of the Delaney gravel are sparsely scattered over Cretaceous limestones. No sand remains with the gravel; consequently, a heavy mineral examination cannot be made.

The position of the Delaney gravel on level surfaces and its constant elevation above the river suggest that it is in place. The Delaney gravel is approximately 50 feet higher than the Asylum terrace and must represent an older stage of Colorado River.

Asylum Terrace.—The Asylum Terrace ranges from 160 feet above the Colorado River at La Grange to 190 feet at Austin. It has been definitely traced from 6 miles northwest of Austin downstream to La Grange, and possibly as far as Altair. The terrace deposit contains cobbles and boulders of flint, chert and quartz and pebbles of limestone, quartz, feldspar and flint in a sand composed mostly of quartz and feldspar. The material is cross-laminated and somewhat assorted. Its present thickness averages about 3 feet, and the maximum thickness is about 15 feet.

Capitol Terrace.—The Capitol Terrace ranges from 77 to 120 feet in height above Colorado River within the area investigated. Its composing materials are essentially the same as those of the Asylum terrace, but the terrace is more extensive, better preserved, and is traceable throughout the entire area.

Sixth Street Terrace.—The Sixth Street Terrace, according to Deussen, can be traced from the lower part of the Coastal Plain, where it is 52 feet above the river, to Austin, where it is 75 feet above the river. The portion of the lower part of the Coastal Plain meant by Deussen is not clear, but from the height given, it is probably in the vicinity of Altair. The terrace has been covered by the water of Lake Austin between Tom Miller Dam at Austin and Cameron Ferry.

The deposits forming this terrace consist in part of cobbles 2 to 3 inches in diameter, similar to those in the older terraces. Mostly, however, the deposits are material less than $1\frac{1}{4}$ inches in diameter. In this investigation the terrace was first recognized at Altair by the pebble sizes.

First Street and Lower Terraces.—The First Street Terrace forms the most extensive and agriculturally important terrace on Colorado River. It can be traced continuously, except where covered by Lake Austin, throughout the entire area. It forms the extensively cultivated, rich alluvium flat upon which Bastrop, Smithville, La Grange and Columbus are located.

The Lower Terraces are not as clearly defined as the First Street and older terraces. Two distinct terrace benches at Austin below the First Street Terrace are named by Weeks the Riverview and Sandbeach Terraces respectively. At Bastrop the bench between the First Street and Riverview Terraces is poorly developed or lacking, and at La Grange the Riverview Terrace appears to have been deposited over the Sandbeach Terrace. At Columbus the demarcation between the First Street and Riverview Terraces is again uncertain. The First Street and Lower Terraces have been covered by water at extreme flood stages during recent geologic time. These deposits are largely silt and sand, but numerous lenses of pebbles and cobbles are found throughout, particularly, in the lower two benches.

HEAVY MINERALS OF COLORADO RIVER TERRACES

Methods of Analysis

Thirty grams of each sample were taken for analysis. Clay and silt particles were removed by decantation, and the sand was sieved through Tyler standard screens, separating the particles into grade sizes of 2 mm. and larger, 1–2 mm., $\frac{1}{2}$–1 mm., $\frac{1}{4}$–$\frac{1}{2}$ mm., $\frac{1}{8}$–$\frac{1}{4}$mm., $\frac{1}{16}$–$\frac{1}{8}$ mm., and less than $\frac{1}{16}$ mm. No diagnostic characteristics could be detected from histograms of the grade sizes.

The particle size $\frac{1}{4}$–$\frac{1}{8}$ mm. was used for heavy mineral determination. This was the grade which usually occurred beneath the mode in a histogram, and the greatest variety of heavy minerals was consistently found in it. The grains less than $\frac{1}{16}$ mm. in size are mostly black opaque minerals and zircon. Their abundance tends to obscure the ratios of the

more diagnostic minerals, and, consequently, they were not included in the heavy mineral count.

The heavy minerals were separated by using bromoform having a specific gravity of 2.9. Many of the heavy minerals in terraces overlying Tertiary formations were iron stained. The iron was removed by boiling in dilute hydrochloric acid. The heavy mineral residue was mounted in Canada balsam and 200 grains were counted in each slide.

Heavy Minerals

The materials of terraces analyzed contain the same heavy mineral suites, namely: hornblende; black opaque minerals consisting chiefly of magnetite, ilmenite and possibly some chromite; kyanite; epidote; zircon; garnet; tourmaline; staurolite; rutile; leucoxene; and limonite. The proportion of these minerals differs considerably among the various terraces as well as within the terraces above and below the Cretaceous-Tertiary contact.

Asylum Terrace.—Fourteen analyses were made of the sediments of the Asylum Terrace. Most of the samples taken near Austin contained about 4 per cent of hornblende. A sample collected along Manor Road west of Little Walnut Creek contained 11 per cent. The hornblende content of this sample varied far more than in any other sample. Samples collected downstream from the Cretaceous-Tertiary contact consistently contain 1 or 2 per cent of hornblende. This decrease is probably accounted for by dilution from non-hornblende bearing Tertiary rocks.

The deposits of the Asylum Terrace in most places contain feldspar grains and pebbles. However, three samples, one from 3.5 miles south of the Bastrop Park entrance, one from 18 miles northwest of Columbus, and one from 1 mile east of Ellinger, contained little or no feldspar. Within a few miles of each locality feldspar is present. Nothing was seen to explain its absence and no discrepancies were noticed in the heavy mineral suites.

Deussen followed the Asylum Terrace by profile from Austin to the flat 5.9 miles north of La Grange. Heavy mineral analyses verify his work. Two samples were collected from terrace deposits capping ridges between La Grange and Columbus which Deussen believed to be the Capitol Terrace. They are, however, higher and farther from the river than is normal for the Capitol Terrace, and the heavy mineral suites show typical Asylum ratios. Another sample collected 3 miles south of Columbus along the Altair highway is from the highest hill in the vicinity and has a mineral suite typical of the Asylum terrace.

A sample of particular interest collected 1½ miles west of Eagle Lake on the Altair highway, is from a gravel deposit in an area so flat that it is difficult to distinguish between any of the terraces above the First Street level. The gravel is composed of pre-Cambrian quartz and feldspar, Edwards flint, and Ellenburger chert, typical of both the Capitol or Asylum Terraces. It is widespread but mostly covered by 14 inches of fine detrital material except in irrigation ditches. The heavy mineral ratio is similar to that found elsewhere in the Asylum Terrace.

Capitol Terrace.—Fourteen heavy mineral analyses were made of samples collected from the Capitol Terrace. Hornblende averaged 10 per cent of the heavy minerals in samples collected from deposits over Cretaceous rocks. A sample from above Cameron Ferry, however, contained a much lower hornblende content. This may be explained by the sample not being truly representative. Below the Cretaceous-Tertiary contact hornblende drops to 5 or 6 per cent of the heavy minerals. Hornblende is more abundant than in the Asylum terrace deposits at corresponding localities, but below the contact the hornblende in the Capitol Terrace deposits is not much different from that of the Asylum Terrace above the contact. The difference between the deposits of the two terraces is

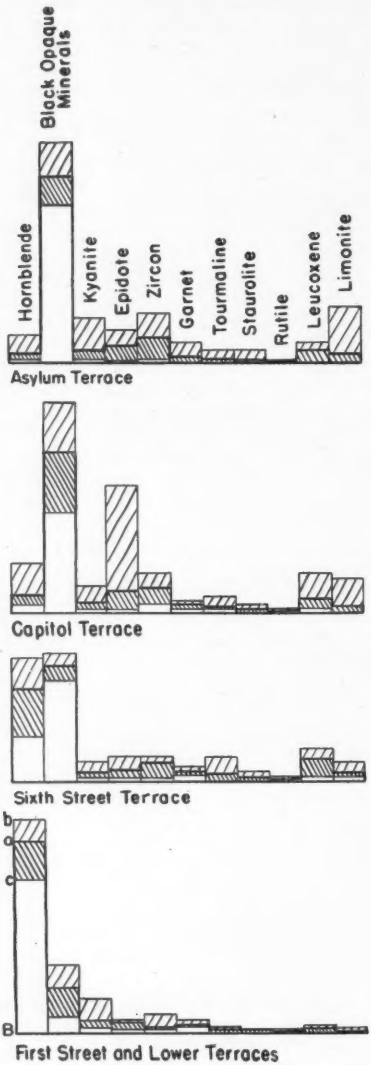

FIG. 1.—Bar charts showing heavy mineral content of Colorado River terraces.

apparent if they are compared throughout their length. (See table which follows.) A sample taken from the escarpment 2.7 miles west of Bastrop contains 45 per cent epidote and 10 per cent kyanite in the heavy mineral suite, which is an extreme concentration of these minerals. Another sample from the same deposit one-half mile upstream showed the usual Capitol Terrace ratios.

Sixth Street Terrace.—Seven Sixth Street Terrace samples analyzed show that the hornblende and black opaque minerals are almost equal in amount. In a few samples hornblende is more plentiful, and in others the black opaque minerals are the most abundant. The average for all of the samples is 32 per cent of hornblende and 39 per cent of black opaque minerals.

First Street and Lower Terraces.—In the deposits of the First Street and Lower Terraces hornblende is in great abundance in all of the heavy mineral suites, being several times greater than the black opaque minerals. The average for 12 samples is hornblende 66 per cent and black opaque minerals 15 per cent. The ratio of hornblende to black opaque minerals is slightly greater, however, in the deposits of the First Street Terrace than in those of the lower benches. Hornblende averages 75 per cent in the First Street Terrace deposits, the black opaque minerals 12 per cent; in the Riverview deposits hornblende averages 66 and black opaque minerals 14 per cent; and in the Sandbeach deposits hornblende averages 63 and black opaque minerals 20 per cent. This relationship suggests that the material in the lower benches was deposited before that in the First Street Terrace. Additional evidence will be needed before this can be accepted.

Correlation of Terraces

Figure 1 is a graphic representation of the heavy mineral percentages of each terrace. The average percentage of the heavy minerals for an entire terrace is

shown by the space from the base line to the line between the two shaded areas. Thus the average percentage of hornblende in the First Street and Lower Terraces is represented by the distance from *B* (base line) to *a* in figure 1. The minimum percentage of hornblende in any sample of First Street and Lower Terraces is shown by the distance from *B* to *c* and the maximum percentage by the distance from *B* to *b*. The variation from the average is extreme in some minerals, as illustrated by epidote in the Capitol Terrace.

Zircon is a stable mineral and the quantity deposited should be essentially the same throughout the terraces represented in figure 1 providing that the degree of weathering of the source rock was essentially the same throughout the time of deposition of this series of terraces. Using this premise, figure 2 was made assuming that the quantity of zircon is the same in all terraces. The variation from figure 1 for hornblende is accentuated markedly, and that of garnet, tourmaline, staurolite, leucoxene and limonite to a lesser degree. The black opaque minerals, such as ilmenite and magnetite, like zircon, are extremely resistant to weathering, and in figure 2, where zircon is plotted constant, they likewise show little variation. Figure 2 is based on an assumption that the source rocks from which the heavy minerals for all the terraces were derived were about equally weathered. However, as pointed out later the earlier terraces probably were deposited under more humid conditions than exist in the area at present, and under such conditions the feldspars, being less stable, would be kaolinized and largely escape being preserved in terraces. This means that a unit of material in the older terrace deposits represents a greater quantity of original rock than does an equal unit of material in the Lower Terraces; consequently, the upper terraces should have a greater quantity per unit of zircon than the Lower Terraces. The true representation of the facts lies somewhere between those shown in figures 1 and 2.

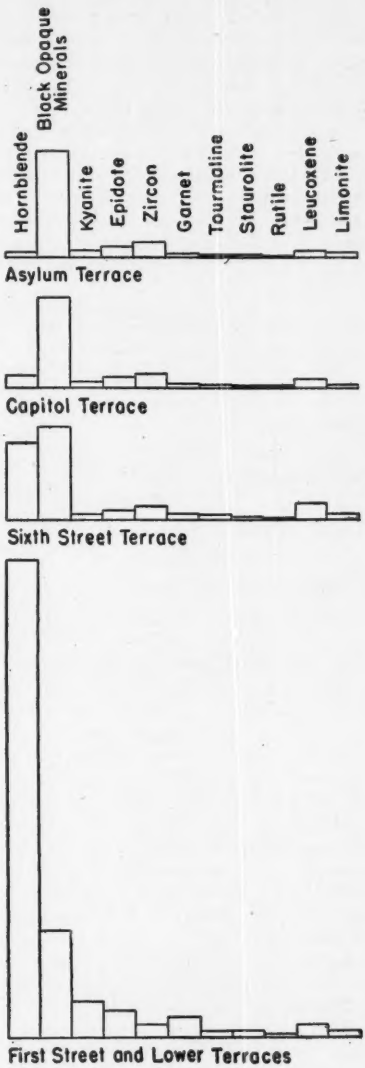

FIG. 2.—Bar charts showing heavy mineral content of Colorado River terraces in relation to a constant zircon content.

The quantities of unstable minerals in the older terraces appear to be less than can be accounted for by the difference in age of the terraces. For this reason it is believed that the older terraces either accumulated more slowly than did the younger terraces or accumulated in a climate more humid than prevailed during the deposition of the younger terraces. It is true, however, that as erosion progresses, the hornblende-bearing rocks of the Central Mineral region are more fully uncovered, and possibly this fact could account for the changes observed in the hornblende content of the various terraces. To check this possibility the ratio of rounded to non-rounded zircons was determined. Much of the zircon from the pre-Cambrian of the Central Mineral region is in non-rounded crystals, whereas most of the zircon derived from the sedimentary rocks is rounded. The ratios found varied some but not in a manner indicating any difference in the amount of minerals derived from the pre-Cambrian rocks. The hornblende grains show no etched patterns along cleavage planes, indicating little weathering *in situ*.

In the following table the ratios of hornblende to this group of minerals is given.

Table showing hornblende-black opaque minerals ratio in analyses upstream and downstream from the Cretaceous-Tertiary contact.

	Upstream from contact	Downstream from contact
Asylum Terrace	$\frac{\text{hornblende}}{\text{opaque}} = \frac{1.1}{10.0}$	$\frac{\text{hornblende}}{\text{opaque}} = \frac{0.25}{10.0}$
Capitol Terrace	$\frac{\text{hornblende}}{\text{opaque}} = \frac{2.2}{10.0}$	$\frac{\text{hornblende}}{\text{opaque}} = \frac{1.0}{10.0}$
Sixth Street Terrace	$\frac{\text{hornblende}}{\text{opaque}} = \frac{13.5}{10.0}$	$\frac{\text{hornblende}}{\text{opaque}} = \frac{7.5}{10.0}$
First Street and Lower Terrace	$\frac{\text{hornblende}}{\text{opaque}} = \frac{49.1}{10.0}$	$\frac{\text{hornblende}}{\text{opaque}} = \frac{43.7}{10.0}$

The effect of the heavy minerals derived from Tertiary rocks is readily detected in the terraces downstream from the Cretaceous-Tertiary contact. Limonite, leucoxene, zircon and the black opaque minerals, as a group, increase at the expense of hornblende.

Conclusions

The terraces of Colorado River can be identified and correlated by the heavy mineral content of their deposits. These terraces, including the Asylum Terrace, can be traced to the coastal prairie at Columbus and perhaps into the flat prairie country as far as Altair. They are in the same order as at Austin, and the older ones do not become overlapped by younger ones.

The low hornblende content of the deposits of the older terraces may be explained by a slow rate of deposition in a climate similar to that of the present or, more likely, to deposition during a much more humid period when chemical weathering was more active. The ratio of rounded to non-rounded zircon crystals is the same in all terraces. This indicates that the zircon contributed by the Central Mineral region has remained practically the same during the deposition of all the terraces.

The First Street and younger terraces are much nearer the same age than any two of the higher terraces. The slight decrease in the percentage of hornblende in the lower benches may indicate that the Colorado River Valley was excavated and then filled to the First Street level,

followed by excavation of the valley fill to form the First Street and Lower Terraces.

In an examination of river terraces occasional heavy mineral suites will be erratic. It is necessary to use sufficient samples to establish a norm of the various minerals present in each terrace; then erratic samples can be detected. It is also necessary to recognize changes in heavy mineral content caused by additions from the underlying rocks and from tributaries entering the river.

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FIGS. 1–2, AUGUST, 1944

SOME STRUCTURAL DIFFERENCES BETWEEN WIND-LAID AND WATER-LAID DEPOSITS ON THE WEST SHORE OF LAKE MICHIGAN

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ABSTRACT

A study was made of beach deposits along the west shore of Lake Michigan for the purpose of determining differences between the wind-laid and water-laid deposits. The bedding is more irregular in the wind-laid than in water-laid material and the lenses vary more in thickness. In individual dunes, sections perpendicular to wind direction show an arching effect in the bedding planes which increases upward. Also the presence of horizontal layers of pebbles indicates water-laid material.

A problem which frequently arises in the study of sandstones is that of distinguishing between subaqueous and subaerial deposits. In such a determination three lines of evidence are usually considered: the fossils, the shape and size of the grains, and the structure. In sandstones, however, fossils are sometimes lacking and grain analysis is time consuming and the conclusions are often indeterminate. Thus, structural evidence is important, and since considerable physical differences exist between the conditions under which subaqueous and subaerial deposits are formed, the two should show distinctive structural differences.

Along the east side of Lake Michigan is a plentiful supply of sand which is constantly being reworked. Because of variation in precipitation and evaporation, the lake level rises and falls several feet over a period of years. As this takes place various shore structures such as beach ridges, spits, and bars are formed at the different water levels. Superimposed on these in many places are wind-laid sands which are often in the form of dunes. As these shore sands are reworked by the waves, previously formed deposits are disturbed and slumping occurs which often results in the formation of nearly vertical cliffs several feet high. The sectional views thus exposed of water-deposited sediment overlaid with dune material gives an excellent opportunity to compare the structure of the two.

The damp sand stands vertically for some time after slumping and when such a section is exposed to the action of the wind for a few hours, the bedding and structure are clearly brought to view. A considerable aid to the observation of such structures along the Lake Michigan shore is the presence of heavy black sand which separates from the lighter material and shows distinctly because of its color. This sand appears differently in the two types of deposits: standing out more boldly and often in thicker layers in the water-laid material. Usually the sections produced by the slumping are approximately perpendicular to the direction of the wind and waves, but they sometimes stand at other angles and in a few cases are parallel with the direction of the wind movement.

The distinguishable differences in structure between the two types of deposits depends on essential differences in the action of water and wind. Water-laid deposits are relatively more uniform in their bedding, more sharply defined, and, generally, more continuous than the material of the foredunes. The water-laid material is deposited in two ways. It is either dropped from suspension or is transported and distributed as masses of sand which travel over the bottom as a result of the energy furnished by currents

and waves. The former is the principal method by which deposits are laid down below wave base. Such deposits are essentially horizontal except for the original slope of the bottom. On the shelf between wave base and the shoreline both processes are active and both horizontal and crossbedded deposits are formed but even here the horizontal deposits are more irregular and less continuous than in deep water. In beach ridges and related structures, mass transportation by wave energy predominates over settlement from suspension. This is the most difficult water-laid type to distinguish from wind-blown material. In subaqueous dunes the ratio between thickness and horizontal extent is less than that of subaerial dunes. Also the cross-lamination which results from deposition of material on their forward slopes is more uniform and the separating surfaces are more parallel plane surfaces than with wind-deposited material. Subaqueous dunes are from fractions of an inch to a few feet in thickness but subaerial foredunes are from about three or four feet to twenty or thirty feet in height.

The surface on which deposition occurs in the foredunes is more irregular than the lake bottom and wind currents are more irregular and variable than water currents. Consequently the lenses in sand dunes, and especially in the foredunes, are generally more irregular and in some places less sharply defined than in water-deposited material. They also vary more in thickness and commonly thin out at the edges more quickly than in the water-deposited material.

Distributed irregularly in the foredune ridge are numerous individual mounds. These have a characteristic structure by which they can be distinguished from water-laid material. A diagrammatic section perpendicular to the prevailing wind direction is shown in figure 1. It will be noticed that the lowest bedding planes are horizontal or nearly so, but as the elevation increases the successive sand lenses increase in thickness toward the center. This produces a structure which is opposite to that known as supratenuous. (See Fig. 2.) Such an arrangement does not seem to agree with the commonly accepted ideas of wind deposition. Ordinarily we would expect this kind of deposit to become thinner with elevation because of greater wind velocity with increasing distance above the surrounding surface. However, a consideration of the prevailing condition shows that here the wind velocity is probably greater at the base of the mounds than near their tops. The wind over a water surface has a more uniform velocity than over a land surface. As it reaches the shore and encounters the foredunes it is forced upward and crowded in beneath the upper moving air layers. This has the effect of reducing

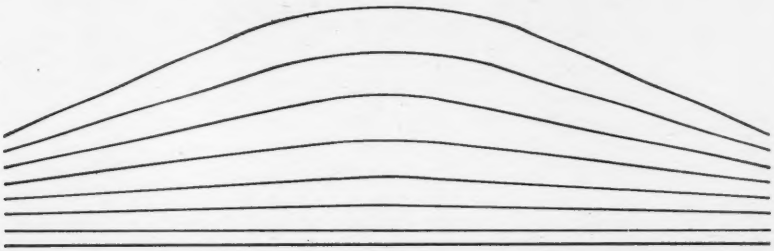

FIG. 1.—The lowest bedding planes are horizontal, or nearly so, but as the elevation increases the successive sand lenses increase in thickness toward the center.

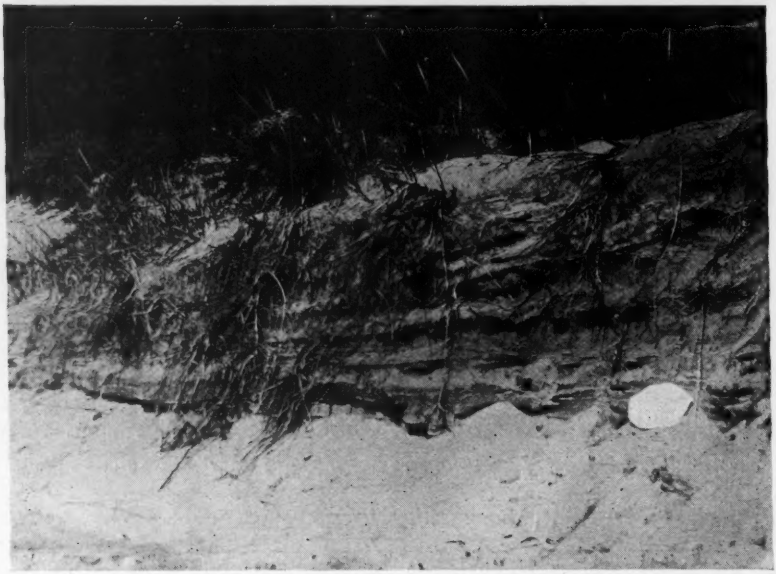

FIG. 2.—Section through dune at right angle to wind direction.

the area of cross-section and so brings about an increase in velocity. Also the individual mounds of sand partly block the path of the lower winds and further increase their velocity as they are forced through the intervening depressions. Another factor in causing an increase in thickness of the layers with elevation may be the variation in direction of the winds. Although the winds along this shore have a westerly component, they come from every westerly point and are frequently from northwest or southwest. This has the effect of moving the sand toward the top of the dunes from first one side and then the other but the wind never persists in one of these directions long enough to result in any appreciable sideward movement of the dunes.

An indication of water-laid material is the presence of isolated horizontal layers of pebbles. Wind-deposited material in some cases contains individual pebbles of small size but a collection arranged horizontally is never found within the body of the sand dune. While the presence of such layers is proof that the material is water-laid, unfortunately, their absence does not constitute proof that a deposit is wind-laid since there are many water-laid sands that do not contain pebbles.

Except for the two described above, no criteria were discovered which can be used alone to distinguish the wind-laid from the water-laid material. However, small differences in structure are numerous and give a distinctive appearance which can be determined with considerable certainty by the experienced observer. It is difficult to bring out these minor differences in photographs and so a background of field experience is of great importance in attempting to distinguish between the two types of deposits.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 14, NO. 2, PP. 97–98, AUGUST, 1944

ANNOUNCEMENTS

REVIEW OF PETROLEUM GEOLOGY IN 1943

The Department of Publications of the Colorado School of Mines, Golden, announces the publication of the "Review of Petroleum Geology in 1943" as Volume 39, Number 2 of the *Quarterly of the Colorado School of Mines*. The "Review" is the work of Dr. F. M. Van Tuyl, head of the Department of Geology, with the cooperation of members of the staffs of the Departments of Geology, Geophysics, and Petroleum Engineering at the Colorado School of Mines.

The work comprises 127 pages and includes a list of about 500 references to publications of the year. Included are noteworthy events and developments in the fields of geology, geophysics, geochemistry, geobiology, petroleum engineering, aerial photography, fluorescense and spectroscopy.

The work was compiled through the cooperation of the Research Committee of the American Association of Petroleum Geologists and was presented in part at the 1944 annual convention of the Association at Dallas.

The review is published annually in the *Quarterly*, the first having been published last year in the July number.

The present "Review" may be obtained from the Department of Publications, Colorado School of Mines, Golden, Colorado, at $1.00 postpaid.

UNITED STATES SECTION OF THE PAN AMERICAN INSTITUTE OF MINING ENGINEERING AND GEOLOGY

The First Pan American Congress of Mining Engineering and Geology, organized and directed by the Institute of Mining Engineering of Chile and officially authorized by the Government of Chile and the South American Union of Engineering Associations, was held in Santiago, Chile, January 15 to 23, 1942. The AIME appointed several delegates to this Congress including Edward Steidle and Will Wright. Mr. Wright was selected to head the group and prepared the report on the meetings which was published in *Mining and Metallurgy* of March 1942. Our Government appointed D. F. Hewett to represent the Geological Survey, Elmer Pehrson, the Bureau of Mines, and Will Wright, the State Department. Edward Steidle represented the Commonwealth of Pennsylvania.

At this Congress it was decided to organize a Pan American Institute of Mining Engineering and Geology (PAIMEG) with headquarters in Santiago, Chile. National sections have been organized in Argentina, Bolivia, Brazil, Chile, Peru and Uruguay. This organization naturally wanted the support of AIME and at the February meeting, 1943, at a meeting of the Board, Mr. Albala, the General Secretary of PAIMEG, discussed the object of the organization and their desire for our support. Dr. Mathewson, president, selected a committee to study the matter and after various discussions with the committee as to just what AIME would and could do, the decisions were finally published in the December 1943 issue of *Mining and Metallurgy*.

An annual meeting of the members of PAIMEG will be held in conjunction with that of the February meeting of AIME in New York and a program of papers will be presented on mining, metallurgical and geological subjects in Latin American countries.

PAIMEG is proposed as an autonomous private institution independent of the governments of the Americas. Qualified candidates from commercial organizations, societies, universities, et cetera, which are closely related to the mineral industries are accepted as members. PAIMEG wishes to organize through the

initiative of individuals and private interests without having the necessity, for the time being, of asking help of the governments concerned.

At the annual AIME meeting last February Mr. Wright met with President Mathewson, Secretary Parsons, Edward Steidle and D. F. Hewett and they discussed the possibilities of organizing a national section of PAIMEG in the United States. At Mr. Parsons' suggestion, it was decided to hold an initial meeting in New York on April 19, at the time of the regular AIME Board meeting. Edward Steidle was asked to serve as Chairman of the "steering committee" in accordance with a request from President Rodriguez, PAIMEG, under date of November 10, 1943. A second Congress is scheduled to be held in Rio de Janeiro, Brazil, in October 1944, but will no doubt be postponed for the duration. Future Congresses will be sponsored by PAIMEG.

Chairman Steidle invited 70 men, principally of New York and Washington, who have had some personal contact with the Latin Americas, to attend a steering committee in New York on April 17. He received 43 acknowledgments of which 38 offered to join immediately. Seven additional men sent word indirectly that they would join. Eighteen men reported for the steering committee meeting.

The consensus of the steering committee was that it was most desirable that a National Section of PAIMEG be formed in the United States without further delay. A motion establishing the Section carried unanimously. Upon proper nomination and vote, the following were elected as a National Directorate:

Chairman—Edward Steidle, Dean, School of Mineral Industries, The Pennsylvania State College

Vice Chairman—C. W. Wright, Chief Foreign Minerals Specialist, United States Bureau of Mines

Sec'y-Treas.—A. T. Ward, Mining Engineer, New York City

Directors—D. F. Hewett, In Charge, Section of Metalliferous Deposits, United States Bureau of Mines; M. B. Gentry, Vice President, Freeport Sulphur Company, New York City; T. T. Read, School of Mines, Columbia University; W. E. Milligan, Department of Metallurgy, Yale University.

Members of any mineral industries society in the United States and Canada are eligible to join the National Section. Individuals paying 1944 dues, amounting to five dollars (no initiation fee) before December 31, 1944, will be recorded as Charter Members. The Chairman was requested to make this known to interested people through the medium of the various publications in the field of the mineral industries, including societies and other technical organizations. At this stage, membership must be based on willingness to aid in bettering good will and better understanding among mineral industries engineers and technologists in the Western Hemisphere. Anyone interested in joining PAIMEG as a charter member is requested to forward dues to Edward Steidle, Chairman, National Directorate, PAIMEG, State College, Pennsylvania, or to Arthur T. Ward, Secretary-Treasurer, National Directorate, PAIMEG, 50 Church Street, New York City. Minutes of the organization meeting will be forwarded to all members.

REVIEW

J. M. DALLAVALLE. *Micromeritics. The Technology of Fine Particles.* Pitman Publishing Company, New York and Chicago, 1943, pp. XIV, 428.

This work, dealing with small particles in the range from colloidal dimensions to sands, but mainly with particles smaller than sands, contains 18 chapters which are as follows: Introduction, Dynamics of small particles; Shape and size-distribution of particles; Methods of particle size measurement; Theory of sieving and grading of materials; Characteristics of packing; Electrical, optical and some properties; Thermodynamics of particles; Chemical properties of small particles; Flow of fluids through packings; Infiltration and particle-moisture relationships; Capillarities; Determination of particle surface; Muds and slurries; Transport of particles; Theory of fine grinding; Collection and separation of particulate particles from air; and Atmospheric and industrial dust. This list of titles of chapters is given as in this way the contents and scope of coverage of the work seems to be most briefly given. There is a selected bibliography of 39 pages, and two pages in the appendix of "Useful Constants and Conversion Factors of Frequent Occurrence." The treatment is extensively mathematical, as may be surmised from the presence of a list of the "Principal Symbols used in Text and Their Units" consisting of three and a quarter pages. There are no illustrations other than graphs and diagrams, of which there are 100. The book contains 82 tables of mathematical relations. The end of each chapter, except the introduction, consists of several problems applying the numerous formulae developed in the chapter.

This work has application in the fields of sedimentation, soils, ground water geology, drilling, studies of dusts in the atmosphere, silting of reservoirs, ceramics, and probably other fields. The emphasis on mathematics and the presence of numerous formulae and mathematical graphs will frighten some readers. The reviewer commends the work to sedimentationists as one worthy of study.

W. H. TWENHOFEL

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